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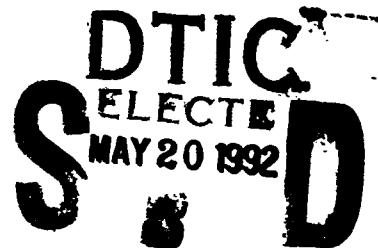
**GRAPHICAL ANALYSIS OF BERTONI'S LOS DATA**

**Andrew Smyth, James Willard, and Julia Steeves**

**ST Systems Corporation  
109 Massachusetts Avenue  
Lexington, MA 02173**

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## **1.0 BACKGROUND**

This report presents new graphical analysis of data originally collected and analyzed by Bertoni (1967). Bertoni's study started with a pilot program conducted from April 1965 to October 1966 to collect actual inflight line-of-sight (LOS) observations. In a pilot program, 72,000 observations were gathered and described by Bertoni. Results of this program provided genuine insight into problems related to Air Force reconnaissance, and search and track, and also provided an initial understanding of the "seeing" environment in which some military electro-optical systems would have to function.

It was determined from the pilot program that realistic estimates of the probability of clear, cloud-free, and hazy lines of sight could be derived from a large sampling of actual inflight observations. Such estimates are required in systems design for determining the utility of optical and infrared weapon, search, track, communication, and target detection systems. The estimates are also required for operational planning.

Consequently, a major effort carried out over a 5-year period from 1969-1974 was initiated. The data used for this paper were the data gathered during the subsequent follow-on program (Bertoni, 1967). The new graphical analysis of the LOS data presented here is meant to provide easily understood statistical information on the effects of cloudy and hazy LOS.

## **2.0 THE DATA BASE**

The data base, known as the 5-year Bertoni LOS data base, consists of 265,280 inflight observations that were mostly obtained over the Northern Hemisphere. Altitudes of observation were generally between 5,000 and 40,000 feet inclusive, although some observation heights exceeded 45,000 feet.

The observations were obtained using a clinometer during flights (see Figure 1 (a)). This instrument was used to read cloudy LOS at a specific inclination angle. The observer would position the instrument at the specified angle etched onto the transparent swivel inside the clinometer and observe the cloudy LOS. If no clouds were seen, the sighting would be marked "1" for clear; if clouds were observed, the sighting would be marked "2" for cloudy. If haze was seen, the sighting would be labeled "3." For each observation, cloudy LOS was recorded at inclination angles of 0° (horizontal view); 30° and 60° (i.e.,

viewing toward sky); -30° and -60° (viewing toward ground) as shown in Figure 1(b). Most of the observations were centered around the midseason months (January, April, July, and October).

Each sighting has a number of parameters associated with it. These parameters are day, month, year, time, latitude, longitude, and altitude.

Because a tristate (cloudy, clear, and hazy) approach was used when assembling the data, two versions of the original data set were assembled to derive the graphical analysis presented here: one with hazy counted as a cloudy LOS condition and the other with hazy counted as a clear LOS condition. In some cases, there are differences significant between the two analyses.

These data were originally tabulated and assembled on punched cards. Card images of the data were then transferred to magnetic tape using the tape structure outlined in Table 1.

**Table 1. Tape Structure Used To Transfer Data to Magnetic Tape**

Tape Number	M8892 (copy=M9488)
Tracks	Nine
Density	1,600 B.P.I.
Label	None
Files	One
Logical Record	40 ASCII 8-Bit Characters
Block Size	4,000 Characters

The data format of a single 40-character logic record on tape is shown in Table 2.

**Table 2. Data Format of a Single 40-Character Logic Record on Tape**

Format	Description
I2	Day
I2	Month
I2	Year
I4	Time (HHMM) GMT
I5	Latitude*100 (0° S to 180° N)
I5	Longitude*100 (0° to 360° W)
I5	Altitude (feet)
5I1	Cloud cover indicators for inclination Angles 0°, 30°, 60°, -30°, -60°, respectively May have values 1 = clear, 2 = cloudy, 3 = hazy Blanks are missing data values
10X	

### **3.0 GRAPHICAL ANALYSIS**

Two statistics are graphed in this report. The first is the probability of a cloudy LOS.

The second statistic is the correlation between lines of sight at different viewing angles. Thus, there is a correlation between LOS at each possible pair of angles for which data existed.

Figures 2 through 69 show graphical analysis of these two statistics for various conditions of altitude, latitude, and time. Time is further stratified by seasons, months, and time of day (Sun time).

### **3.1 CORRELATIONS**

Computed correlation values between lines of sight at various inclination angles in the graphical analysis are tetrachoric correlations. This is the appropriate type of correlation for a variable that is dichotomous, i.e., cloudy or clear. A computer program to compute these tetrachoric correlations was implemented. Occurrences of cloudy or clear events encountered in the LOS data at given inclination angles were compared with LOS conditions seen at other angles and were tallied by the program into 2 x 2 contingency tables. On completion of the tallying process, the contingency tables were sent through a tetrachoric correlation algorithm, Section 3.2, that computed the correlation for each given angular condition. Ten different line fonts were used on the graphs to represent the 10 correlation curves associated with each given angular condition. Thus, correlation of LOS conditions at 0° and -60°, -30°, 30°, and 60° inclination angles are shown (then 30° and -60°, -30°, and 60° followed by 60° and -30° and -60° and finally -30° and -60°). Correlation curves representing each given angular condition are labeled on the right side of each graph at an ordinate position closest to the last ordinate position of the respective curve. A typical label like CORR (30, 60) simply means the correlation curve for LOS events between lines of sight at inclination angles of 30° and 60°.

### **3.2 TETRACHORIC CORRELATION**

The tetrachoric correlation is a quantitative measure of the relationship between two dichotomous variables. The tetrachoric correlation is defined as the correlation in a bivariate normal distribution that would be produced if the continuous normal variables observed were reduced to binary variables by the continuous variable being above or below a threshold. These binary variables can be displayed in a

2 x 2 contingency table. In Table 3, the letters a, b, c, and d are representative of the number of cases in each group.

**Table 3. Contingency Table**

	Below	Above
Below	a	b
Above	c	d

Perhaps the following simplified example may give insight to tetrachoric correlation.

Suppose cloudy or clear LOS was determined only by measuring relative humidity along the LOS. Suppose relative humidity along the LOS was normally distributed, and whenever the line averaged relative humidity exceeded a threshold, a cloudy LOS would occur. Now, if all that can be observed is cloudy or clear, can we calculate the correlation between line weighted relative humidity for separate lines if the original continuous variables are joint normally distributed? Tetrachoric correlation does exactly that.

Many approximations of the tetrachoric correlation have appeared over the years. For example, Panofsky and Brier (1965) give as the formula for the tetrachoric correlation

$$r_t = \sin \left[ \frac{\pi}{2} \frac{\sqrt{ad} - \sqrt{bc}}{ad + bc} \right] \quad (1)$$

This approximation is accurate when both variables have been dichotomized at the median. However, large inadequacies (>20%) can occur where the variables have been dichotomized near the extremes.

This basic equation, eq.(1), is derived from the first term of a Taylor series. Additional terms were added in an algorithm written by A. Boehm of Hughes STX Corporation, which yields a highly accurate estimation of correlation. A FORTRAN version of the algorithm is presented in Appendix A.

### 3.3 PROBABILITIES

Derived probability values that are used to define probability curves of cloudy LOS are simply computed by tallying the number of times cloudy or cloudy-hazy conditions were observed at one of the observing inclination angles and dividing the total by the total number of observations. This probability is labeled on the ordinate of each graph as PROBABILITY (CLOUDY/#DEGREES), which means probability of cloudy LOS given the inclination angle, 0°, 30°, 60°, -30°, or -60°. (The slash [/] on these graphs

represents "given." The traditional vertical bar for representing "given" was not available on the digital plotter used to generate the graphs.) The probability curves are labeled on the right side of the graphs at an ordinate position close to the last ordinate position of each curve. The label PROB (/ -30) means probability curve of cloudy LOS given an observed inclination angle of  $-30^\circ$ . The probability of a clear LOS given one of the observable inclination angles is simply 1.0 minus the probability of cloudy LOS at the same angle.

### 3.4 ALTITUDE

Figures 2 through 7 show correlation curves of cloudy or clear LOS conditions between inclination angles at categorized altitudes of 0 to 5,000 ft, 6000 to 10,000 ft, and so on through category eight, which is 36,000 to 40,000 ft. The ninth category was used for altitudes above 40,000 ft. Two graphs using LOS data archived for all latitudes were produced. The first represents results from the archived LOS data that were modified to consider hazy LOS conditions as cloudy conditions, and the second shows results from the archive where haze was considered a clear condition. Graphs are also presented showing results for LOS data observed at latitudes above  $30^\circ$  N and  $30^\circ$  S.

Figures 8 through 13 show probability curves of cloudy LOS at given inclination angles of  $-60^\circ$ ,  $-30^\circ$ ,  $0^\circ$ ,  $30^\circ$ , and  $60^\circ$  for the same sequence of altitude and latitude categories mentioned above. This set of graphs clearly demonstrates the effect of the presence of haze along the LOS.

### 3.5 LATITUDE

Figures 14 through 25 show correlation and probability curves of LOS conditions for 16 latitude categories. Because of sparse data sampling in the Southern Hemisphere, the category from  $-10^\circ$ – $0^\circ$  actually includes all observations taken in that hemisphere. The next 13 categories are at 5-degree intervals from the equator to the latitude of  $65^\circ$  N. The 14th category combines values from  $65^\circ$  N– $75^\circ$  N, and the last interval combines values from  $75^\circ$  N– $90^\circ$  N.

The graphs are further stratified into three altitude groups consisting of all altitudes, low altitudes (less than or equal to 10,000 ft), and high altitudes (greater than 15,000 ft). Again, two sets of graphs were created for each parameter group, one with hazy equals cloudy and the other with hazy equals clear.

## 3.6 TIME

Figures 26 through 69 show graphical analyses of correlations and probabilities of LOS conditions between inclination angles for seasons, months, and Sun times.

### 3.6.1 Season

The seasons are comprised of four full 3-month intervals consisting of spring (March, April, and May); summer (June, July, and August); fall (September, October, and November); and winter (December, January, and February).

The results (Figures 26 through 29) were generated using LOS data at all latitudes.

### 3.6.2 Month

The analysis by month was done in an attempt to find more detail not seen in the larger seasonal analysis. Unfortunately, most of the sightings were centered around the midseason months January, April, July, and October. The end result, Figures 30 and 31, is a group of points with a very small number of observations and four data points that are quantified. Because of this, the distribution of the data could not satisfy a two-parameter analysis (e.g., altitude and latitude). Instead, additional individual analyses were done, Figures 32 through 49, for latitudes greater than or equal to 30° N, between 30° S and 30° N altitudes less than or equal to 10,000 ft, and finally for altitudes greater than 15,000 ft.

### 3.6.3 Sun Time

Sun time was defined as mean solar time. Mean solar time takes longitude and Greenwich Mean Time (GMT) into account. It is calculated by the equation

$$ST = GMT - \frac{\lambda}{15} \quad (2)$$

Where:

GMT	=	Greenwich Mean Time
$\lambda$	=	Longitude in degrees West
ST	=	Mean Solar Time

(Negative STs are adjusted accordingly.)

Figures 50 through 69 show correlation and probability curves of LOS conditions for the Sun time parameter. The curves are generated by combining LOS data for both altitude and latitude parameters as defined at the top of each graph.

#### **4.0 SUMMARY**

The graphs presented in this report show the variations of probability and correlation of LOS at given angles as a function of altitude, latitude, season, month, solar time, and haze.

These graphs are invaluable in designing, planning, and implementing the use of U.S. Air Force optical and infrared sensors because the use of these sensors can be significantly affected by the presence of clouds or haze.



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Panofsky, H.A. and G.W. Brier, Some Applications of Statistics to Meteorology. (Pennsylvania State University: 1965), pp. 103-104.

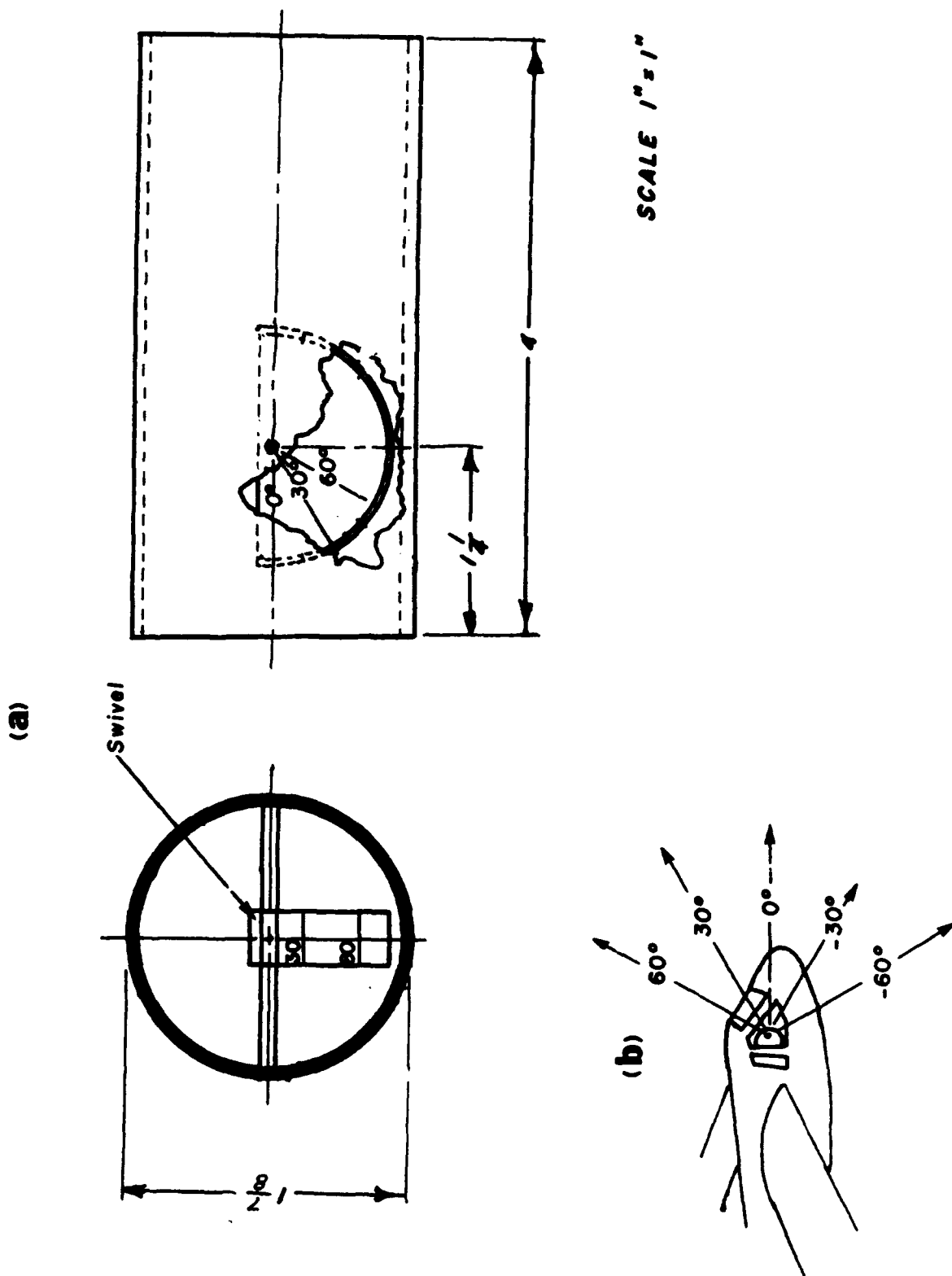


Figure 1. (a) A Clinometer. This Instrument Was Used To Visually Estimate LOS Cloud Cover Amounts at Five Inclination Angles Along Inflight Paths (b).

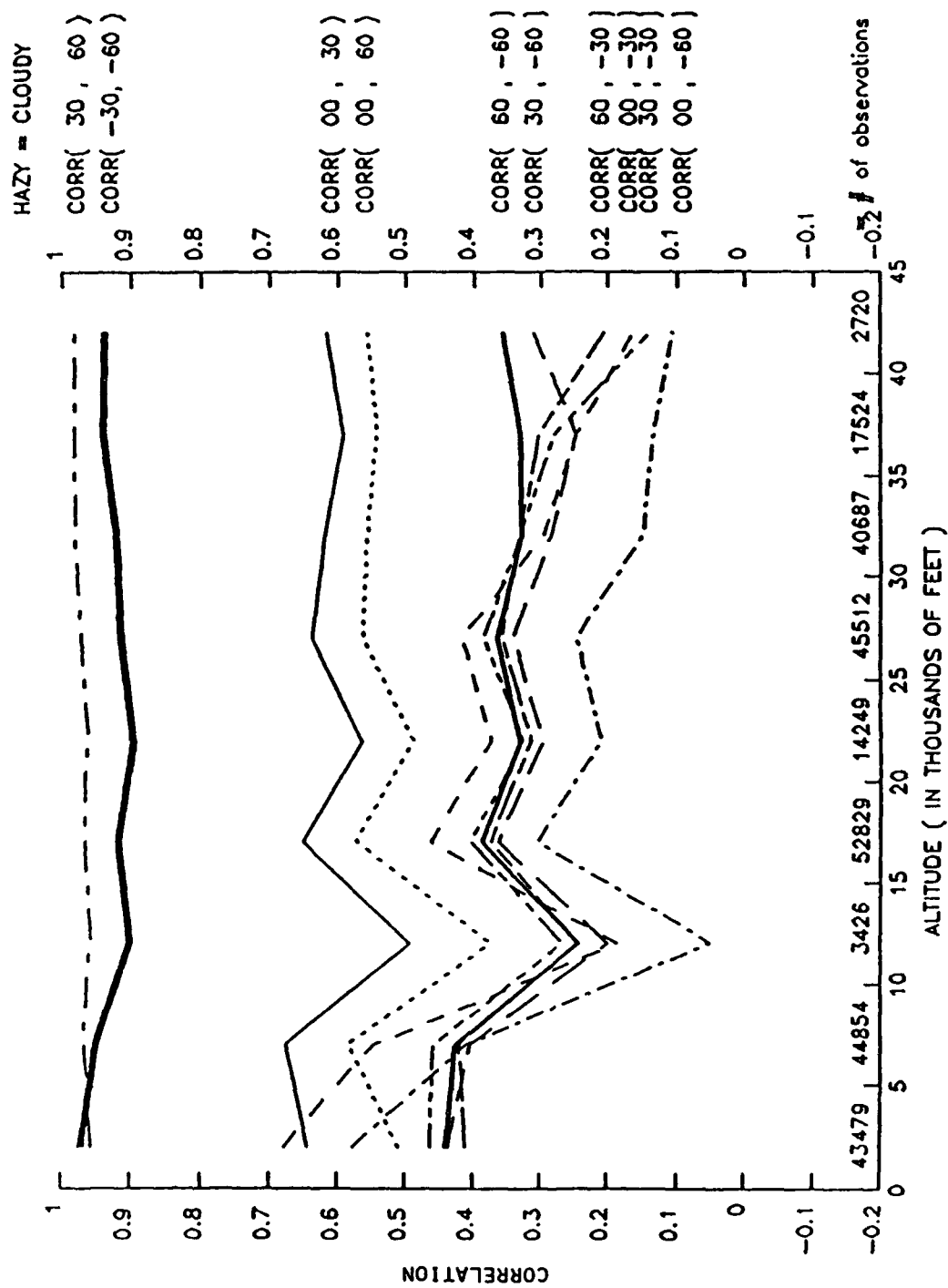


Figure 2. Correlation Between LOS Conditions at Indicated Angles for Various Altitudes. Hazy Is Considered Cloudy. (All Latitudes)

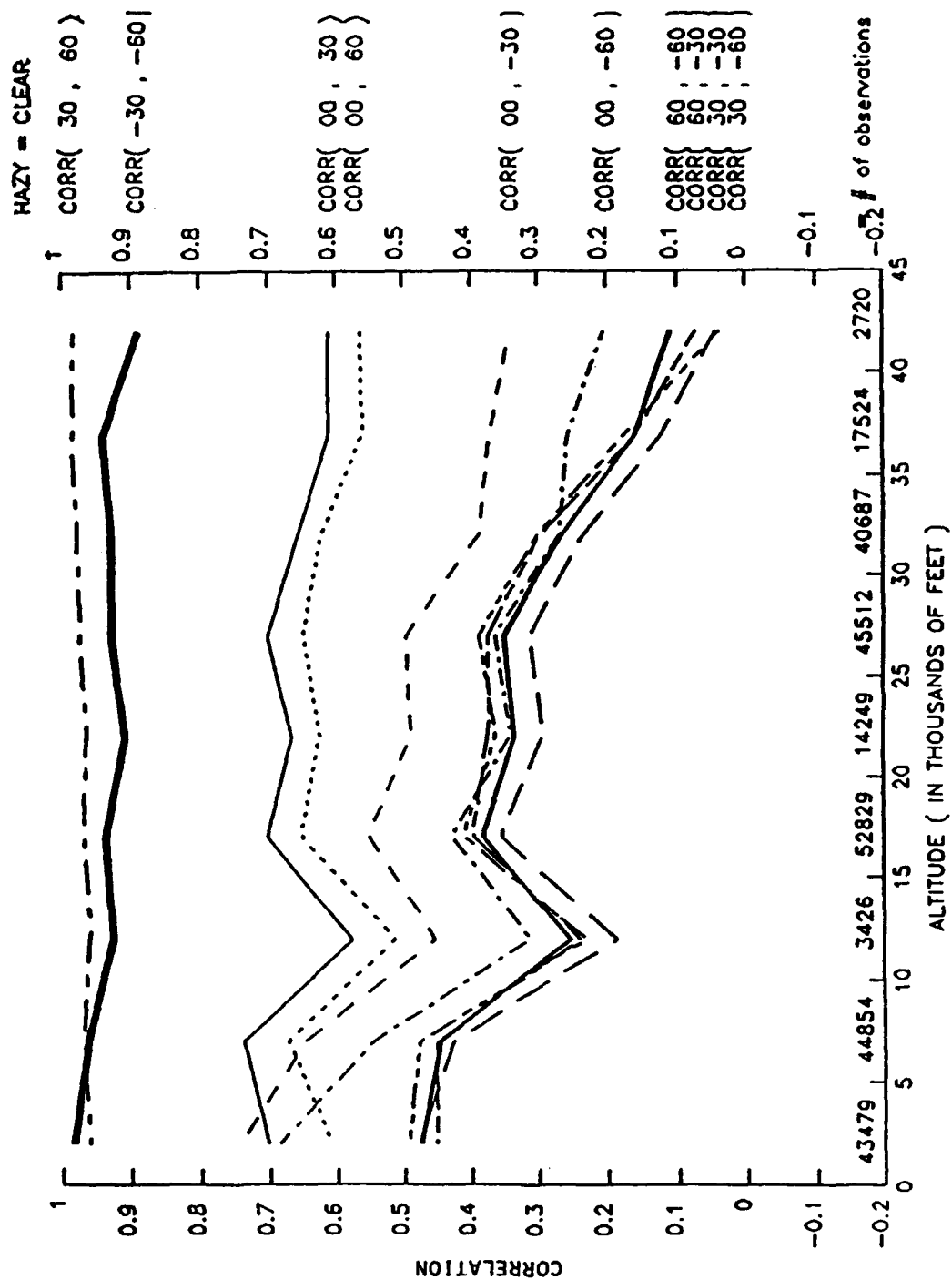


Figure 3. Correlation Between LOS Conditions at Indicated Angles for Various Altitudes. Hazy Is Considered Clear. (All Latitudes)

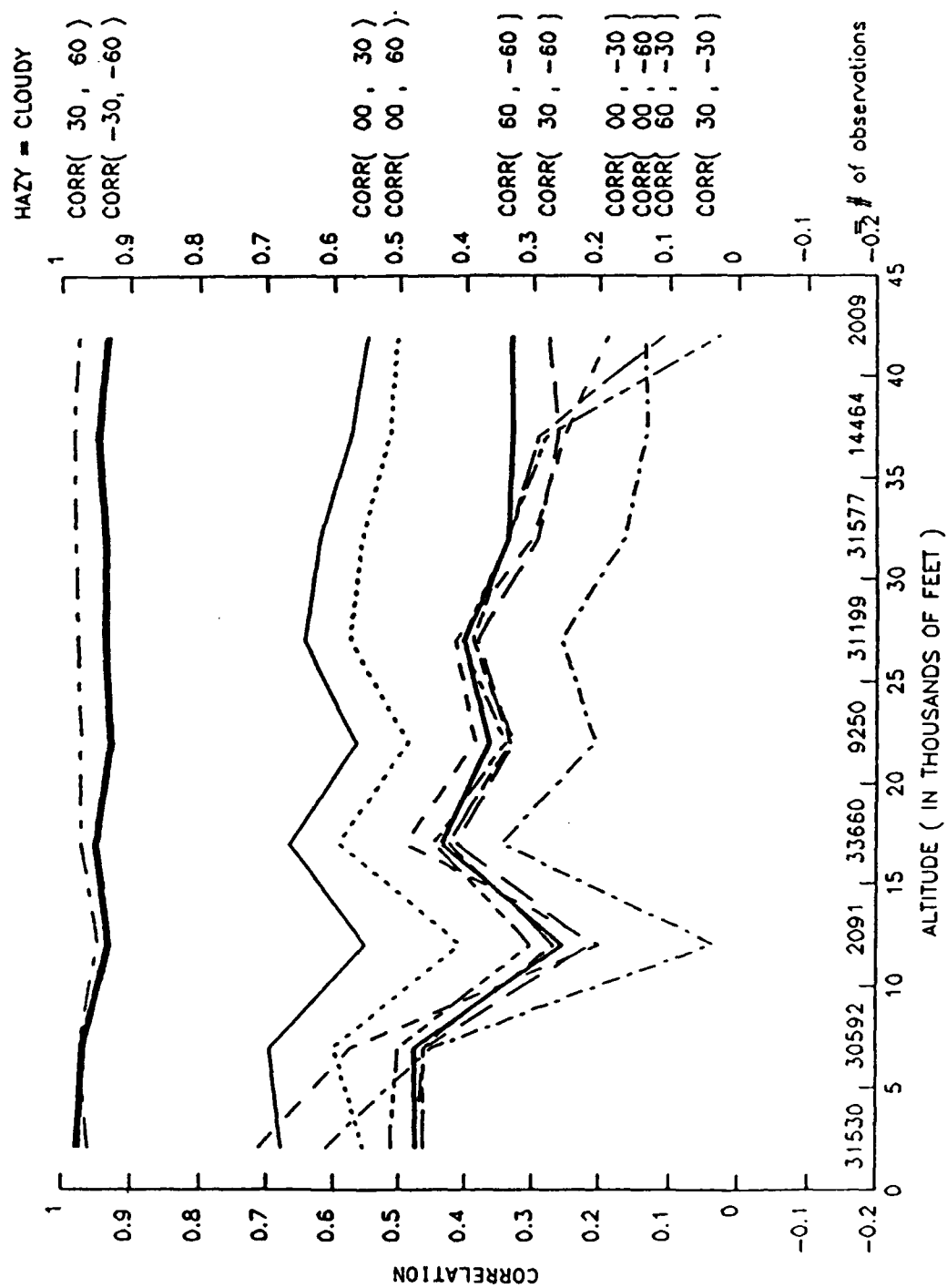


Figure 4. Correlation Between LOS Conditions at Indicated Angles for Various Altitudes. Hazy Is Considered Cloudy.  
(Latitudes  $\geq 30^\circ$  N)

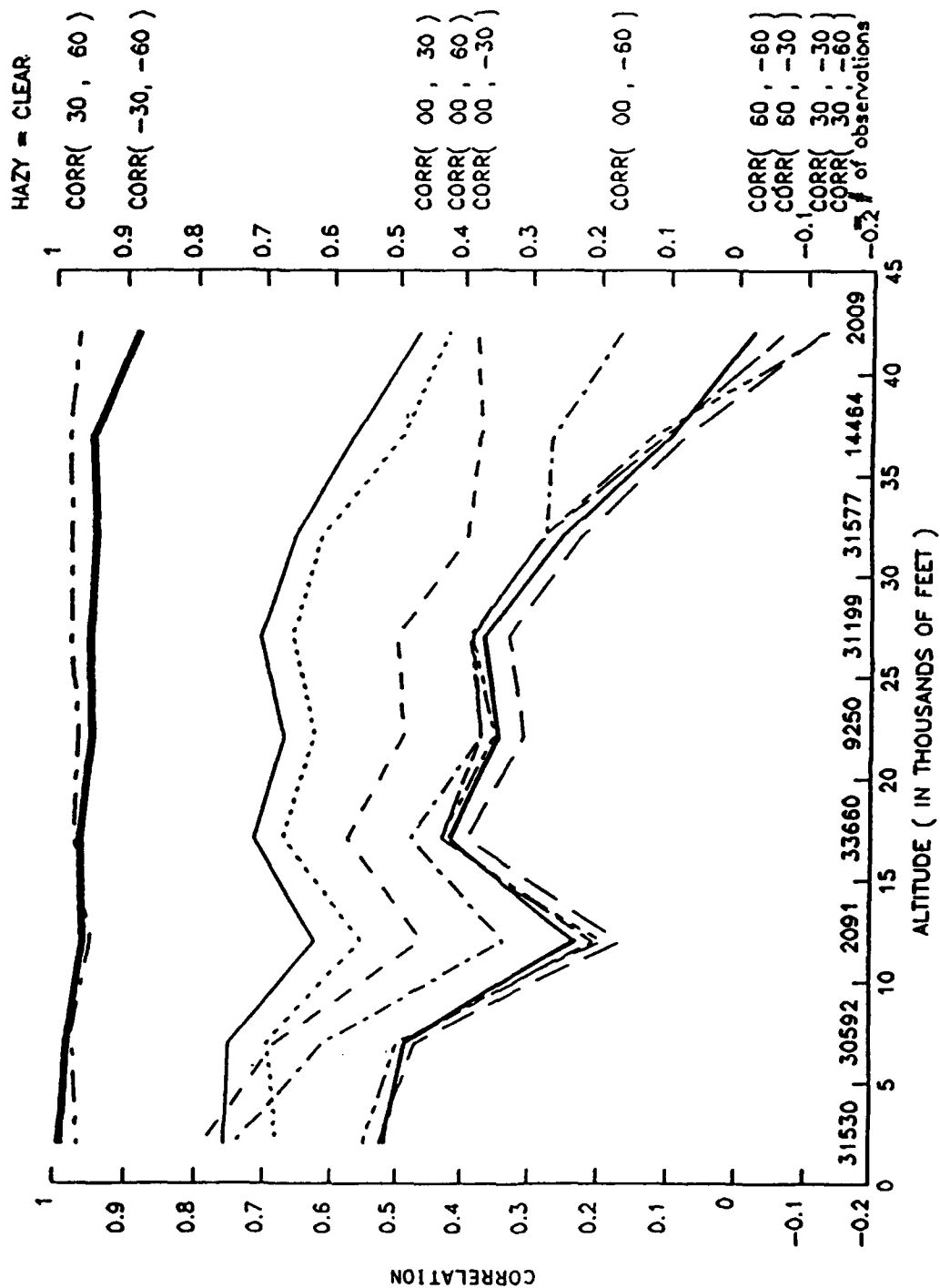


Figure 5. Correlation Between LOS Conditions at Indicated Angles for Various Altitudes. Hazy Is Considered Clear.  
(Latitudes  $\geq 30^\circ$  N)

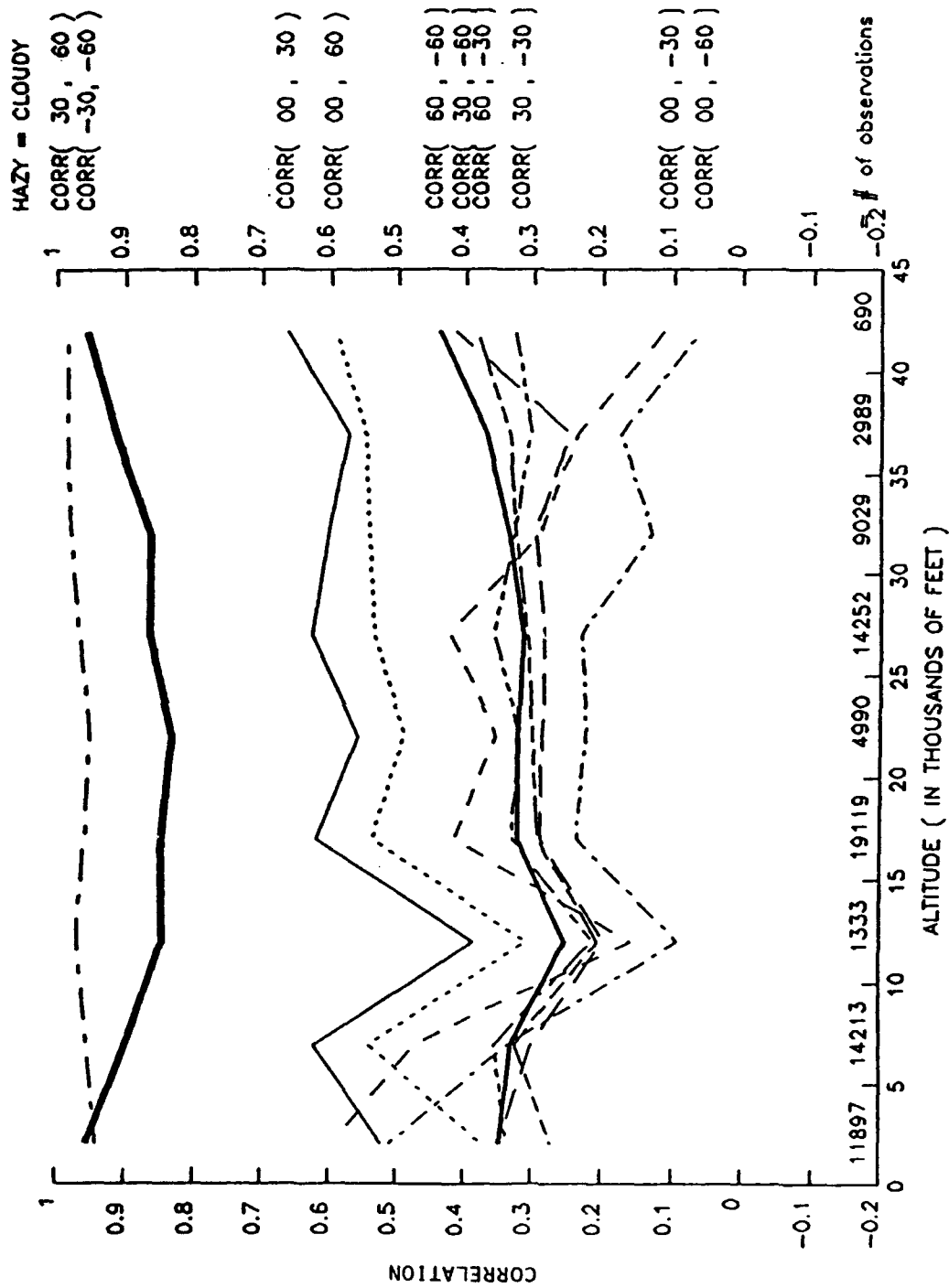


Figure 6. Correlation Between LOS Conditions at Indicated Angles for Various Altitudes. Hazy Is Considered Cloudy.  
(30° S < Latitudes < 30° N)

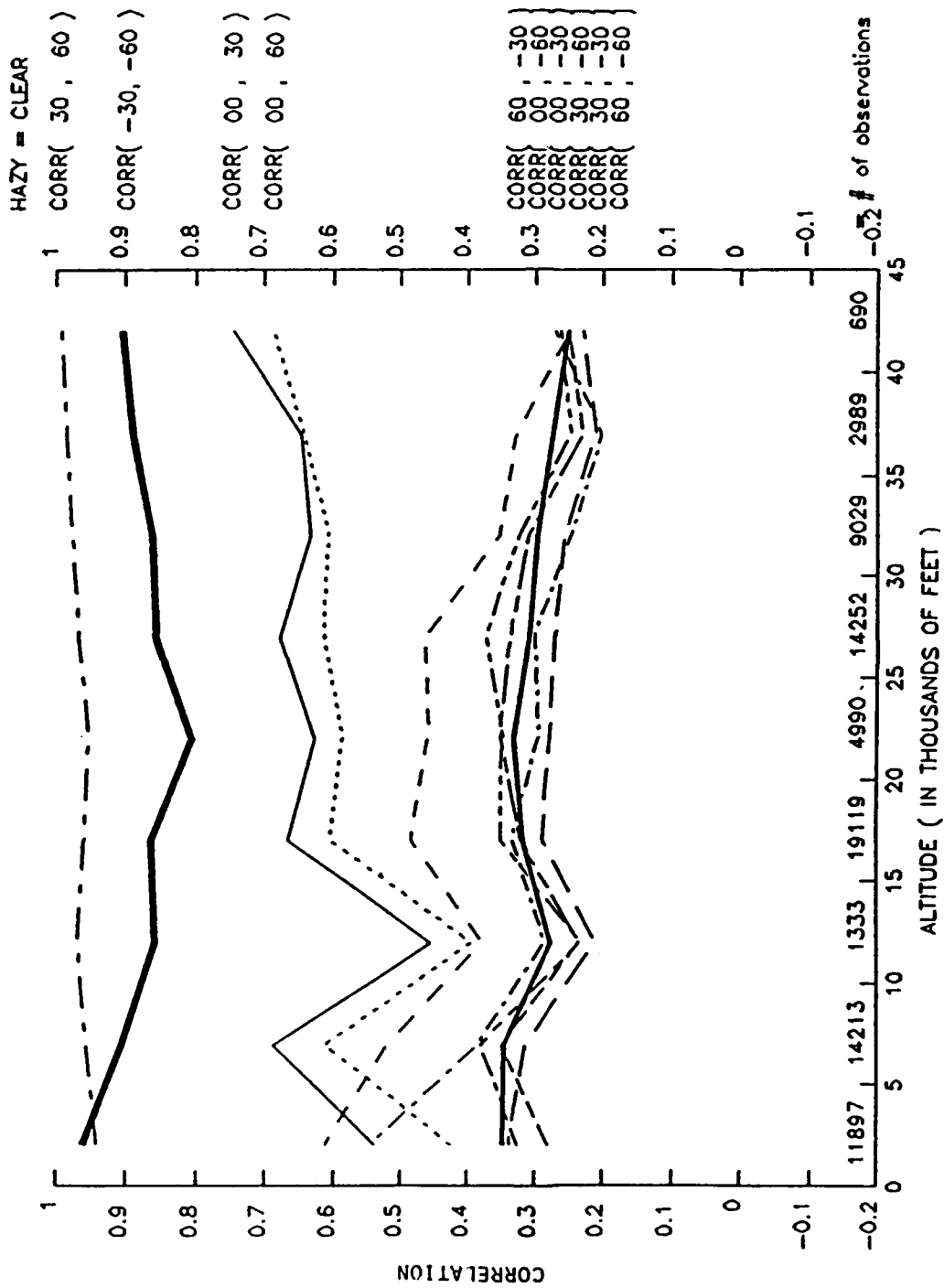


Figure 7. Correlation Between LOS Conditions at Indicated Angles for Various Altitudes. Hazy Is Considered Clear. (30° S < Latitudes < 30° N)



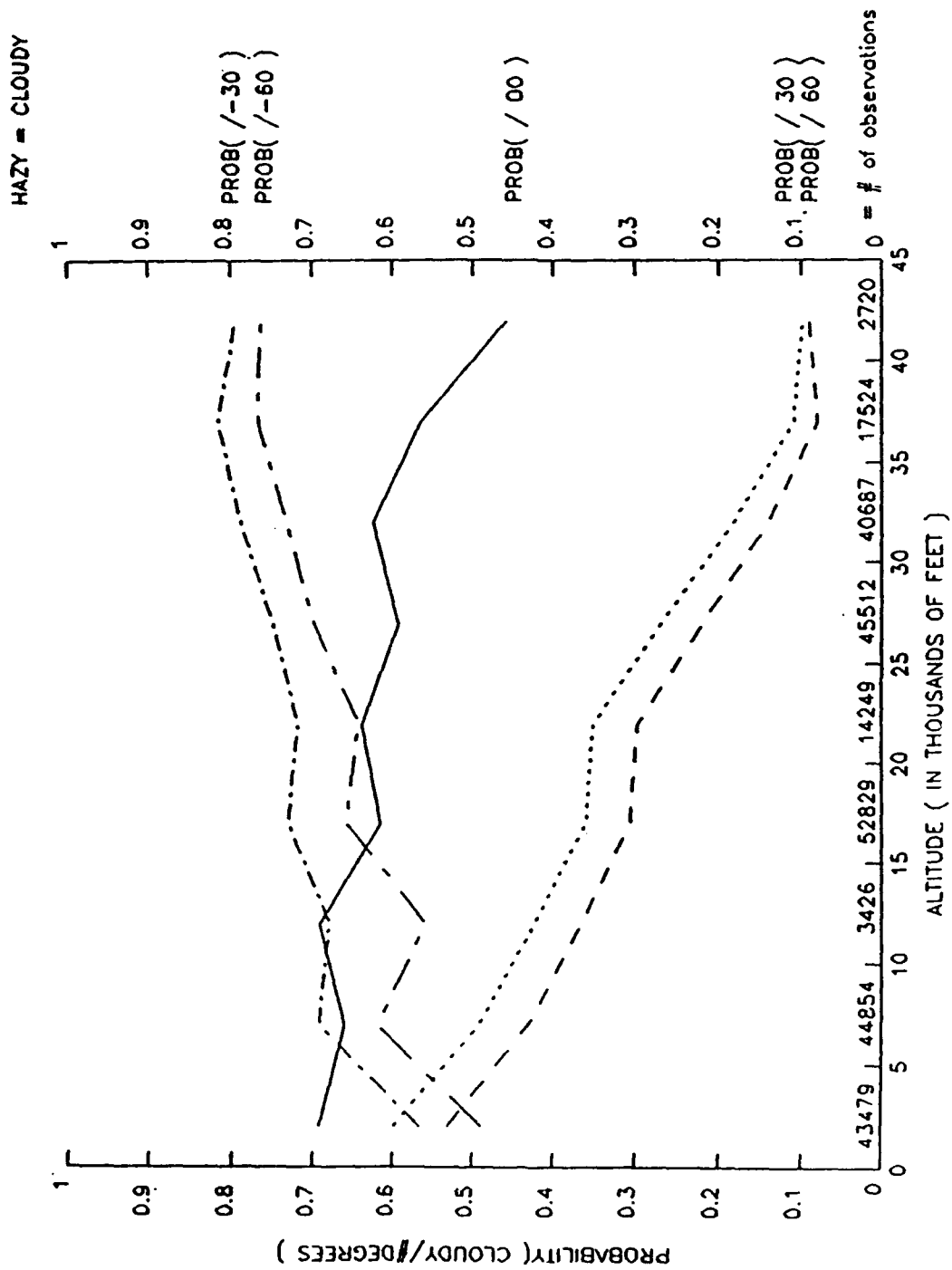


Figure 8. Probability of Cloudy LOS at Indicated Angles for Various Altitudes. Hazy Is Considered Cloudy. (All Latitudes)



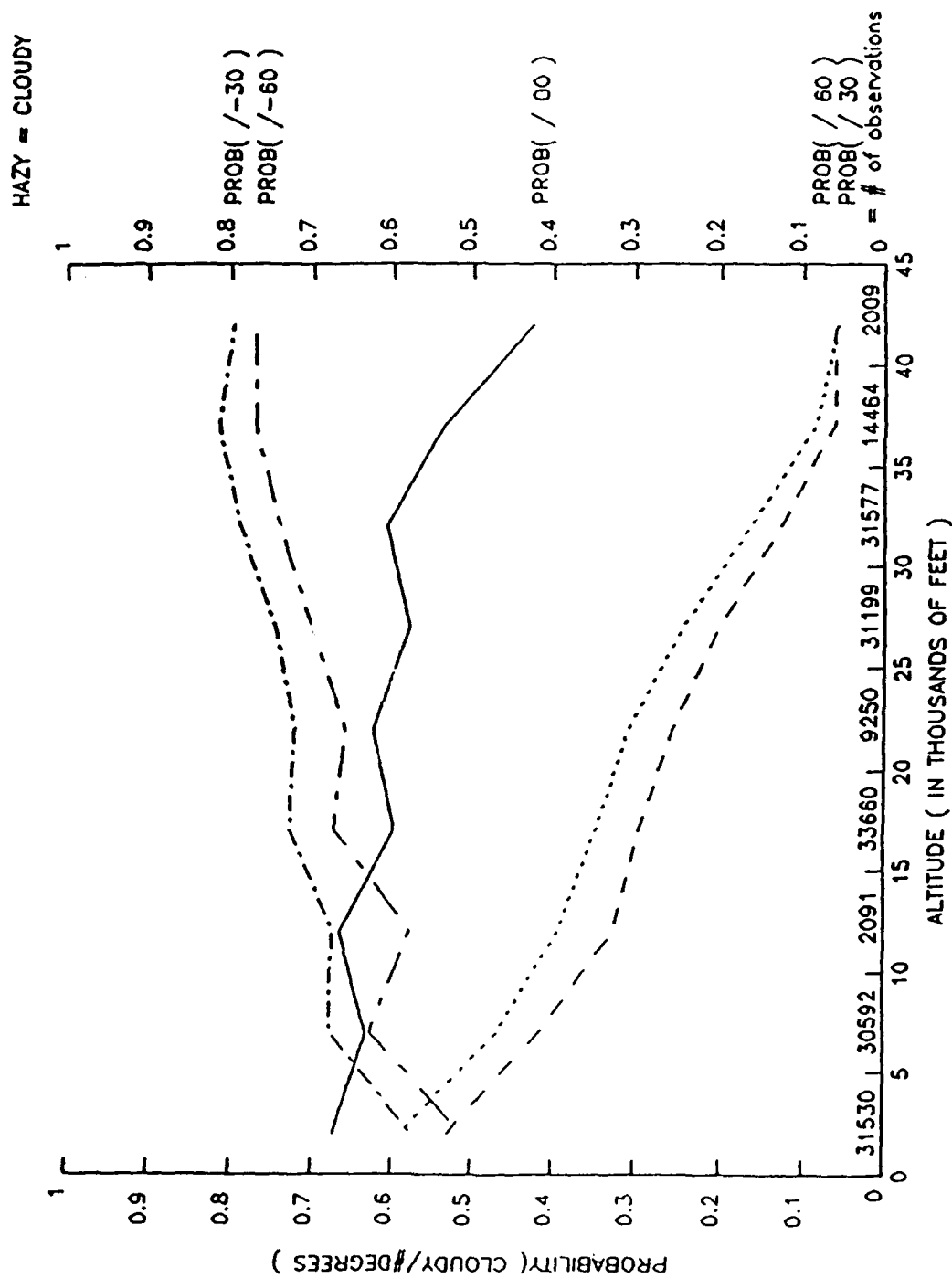


Figure 10. Probability of Cloudy LOS at Indicated Angles for Various Altitudes. Hazy Is Considered Cloudy. (Latitudes  $\geq 30^\circ$  N)

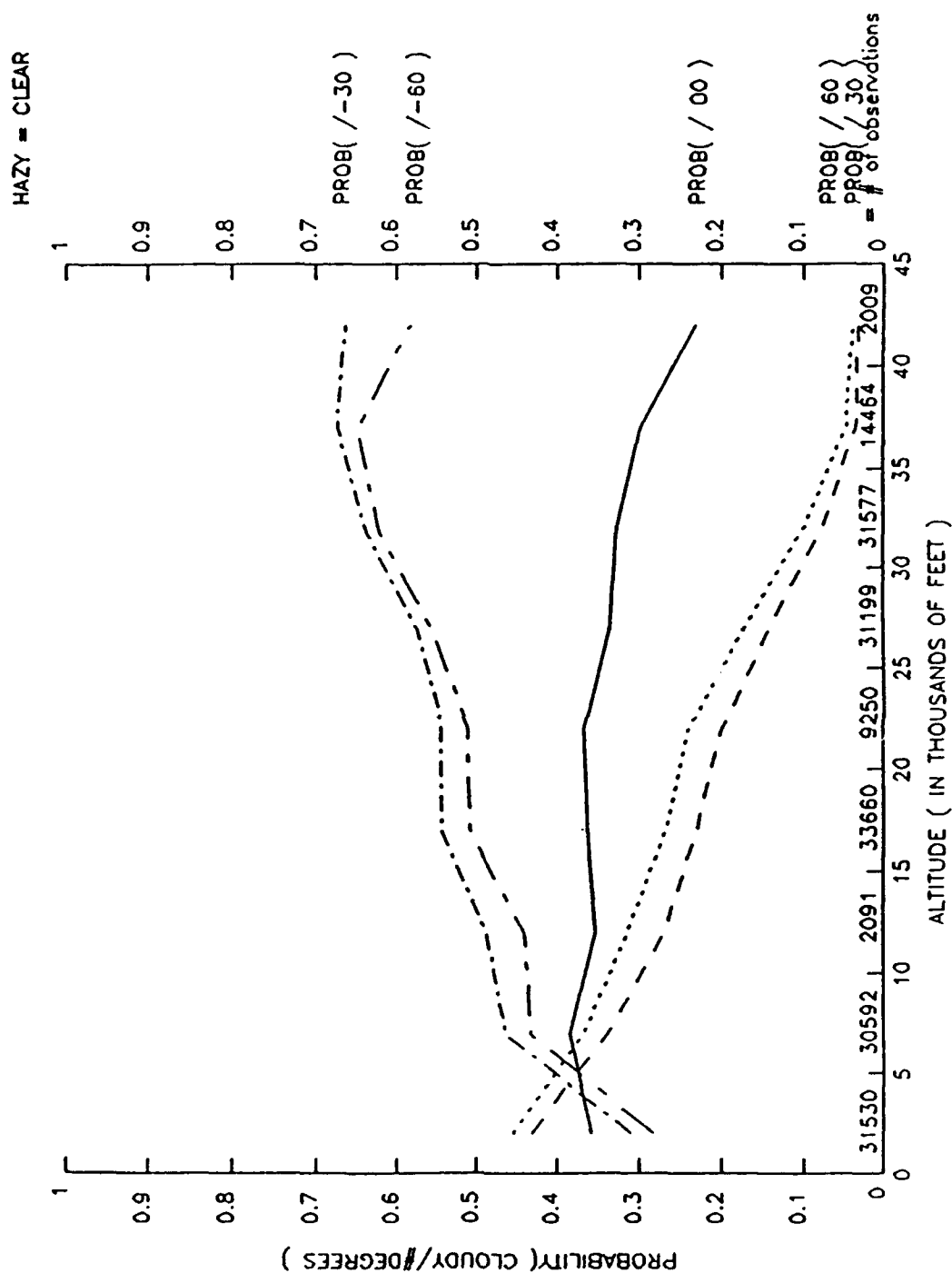


Figure 11. Probability of Cloudy LOS at Indicated Angles for Various Altitudes. Hazy Is Considered Clear. (Latitudes  $\geq 30^\circ$  N)

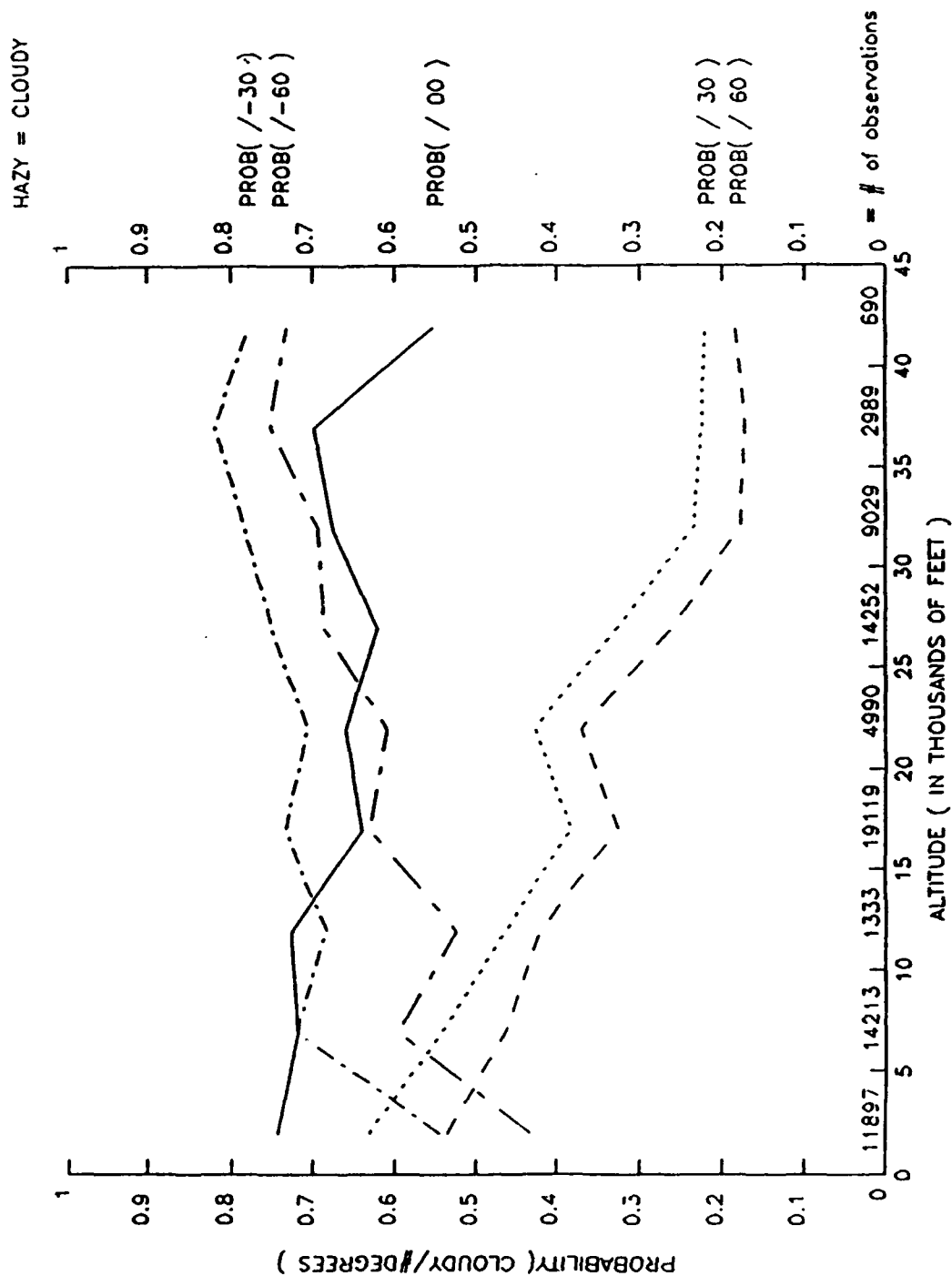


Figure 12. Probability of Cloudy LOS at Indicated Angles for Various Altitudes. Hazy Is Considered Cloudy. (30° S < Latitudes < 30° N)

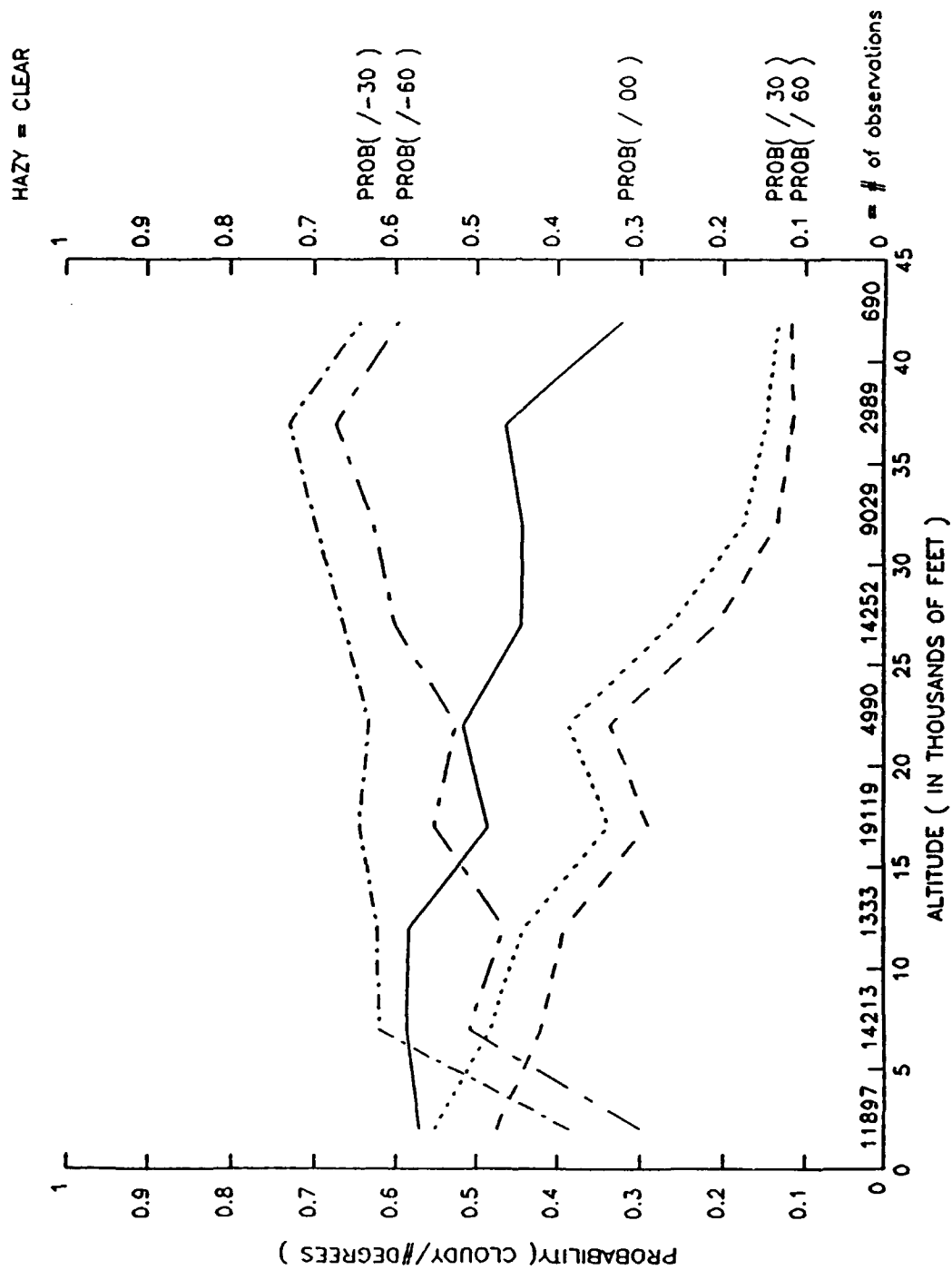


Figure 13. Probability of Cloudy LOS at Indicated Angles for Various Altitudes. Hazy Is Considered Clear. (30° S < Latitudes < 30° N)

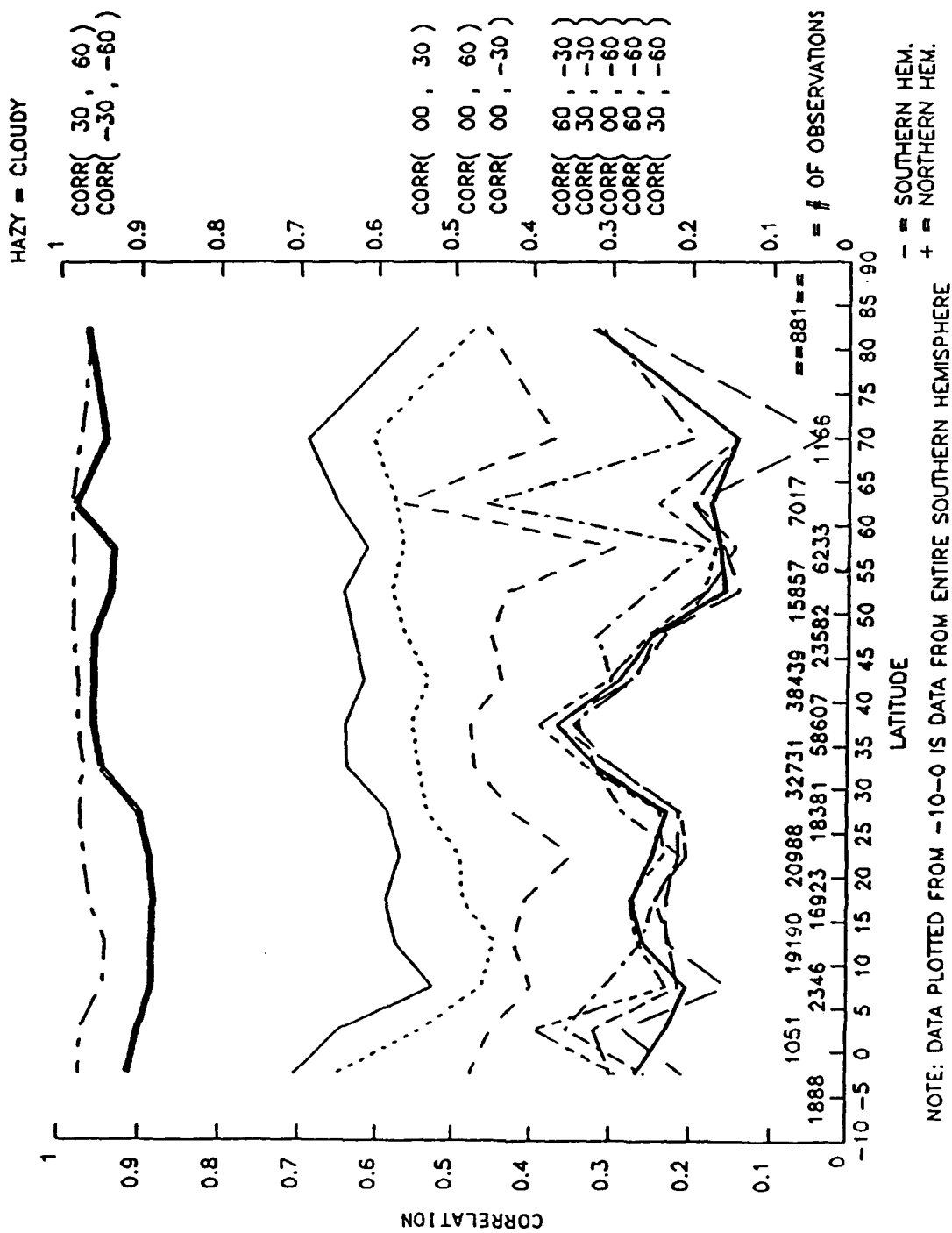


Figure 14. Correlation Between LOS Conditions at Indicated Angles for Various Latitudes. Hazy Is Considered Cloudy. (All Altitudes)

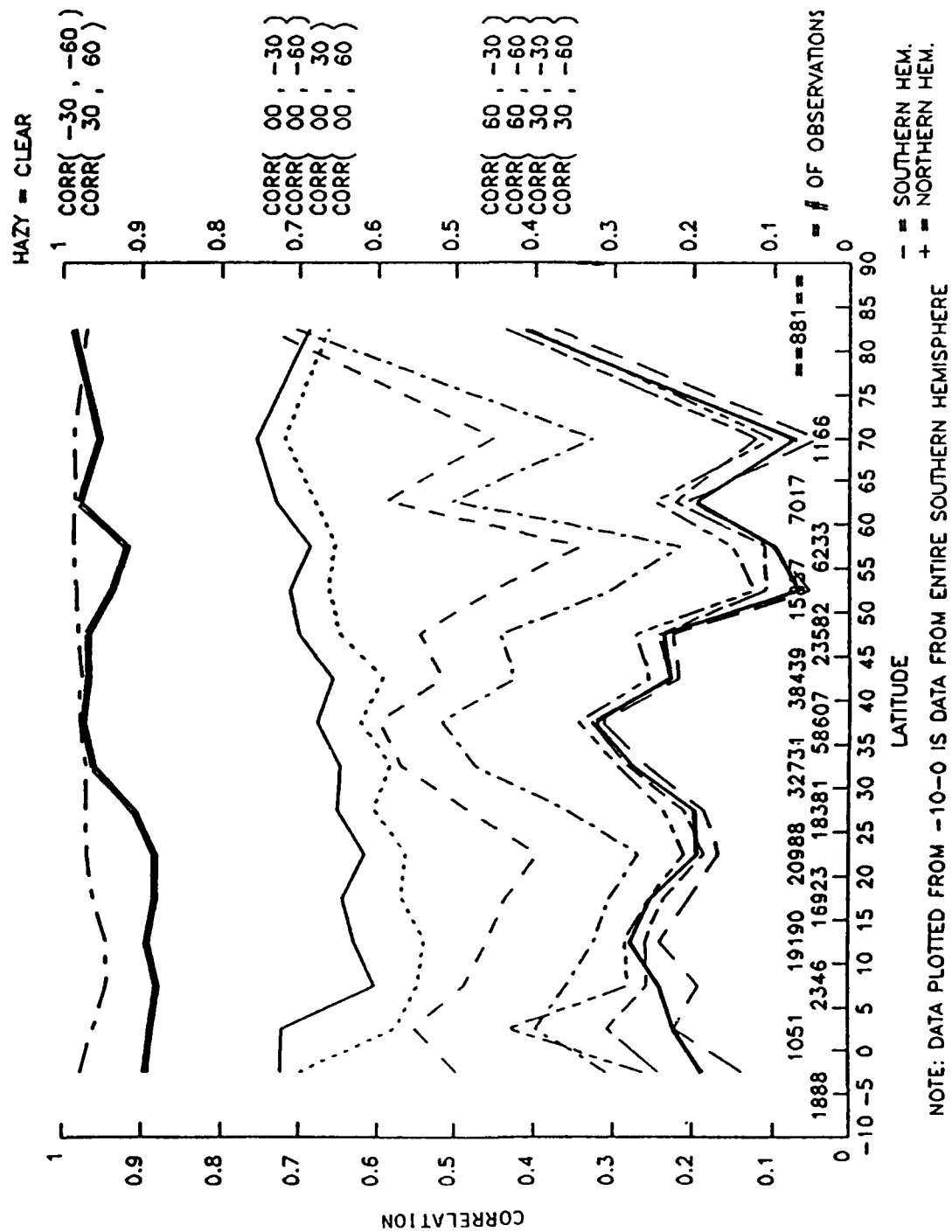


Figure 15. Correlation Between LOS Conditions at Indicated Angles for Various Latitudes. Hazy Is Considered Clear. (All Altitudes)



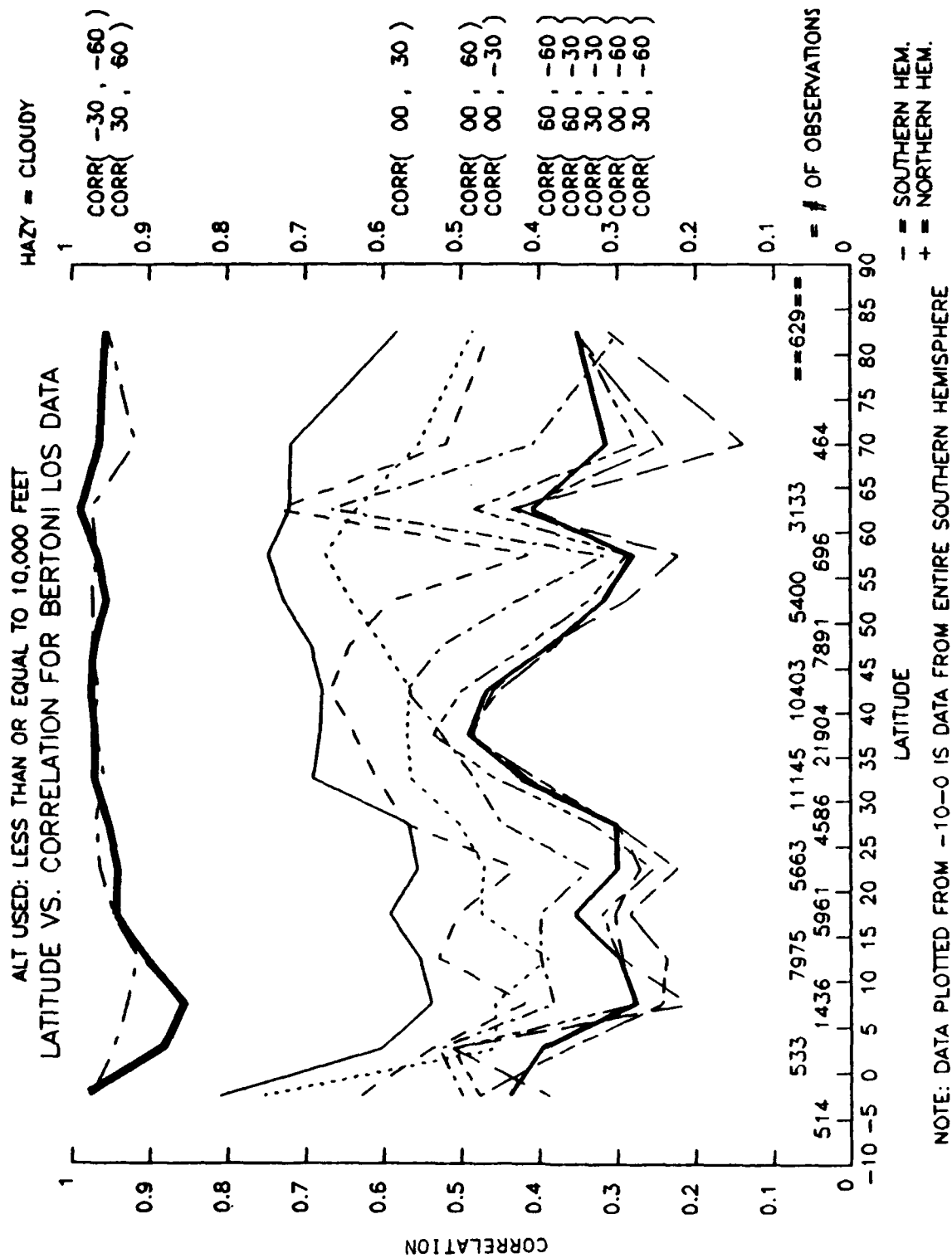


Figure 16. Correlation Between LOS Conditions at Indicated Angles for Various Latitudes. Hazy Is Considered Cloudy.  
(Altitudes  $\leq 10,000$  ft)

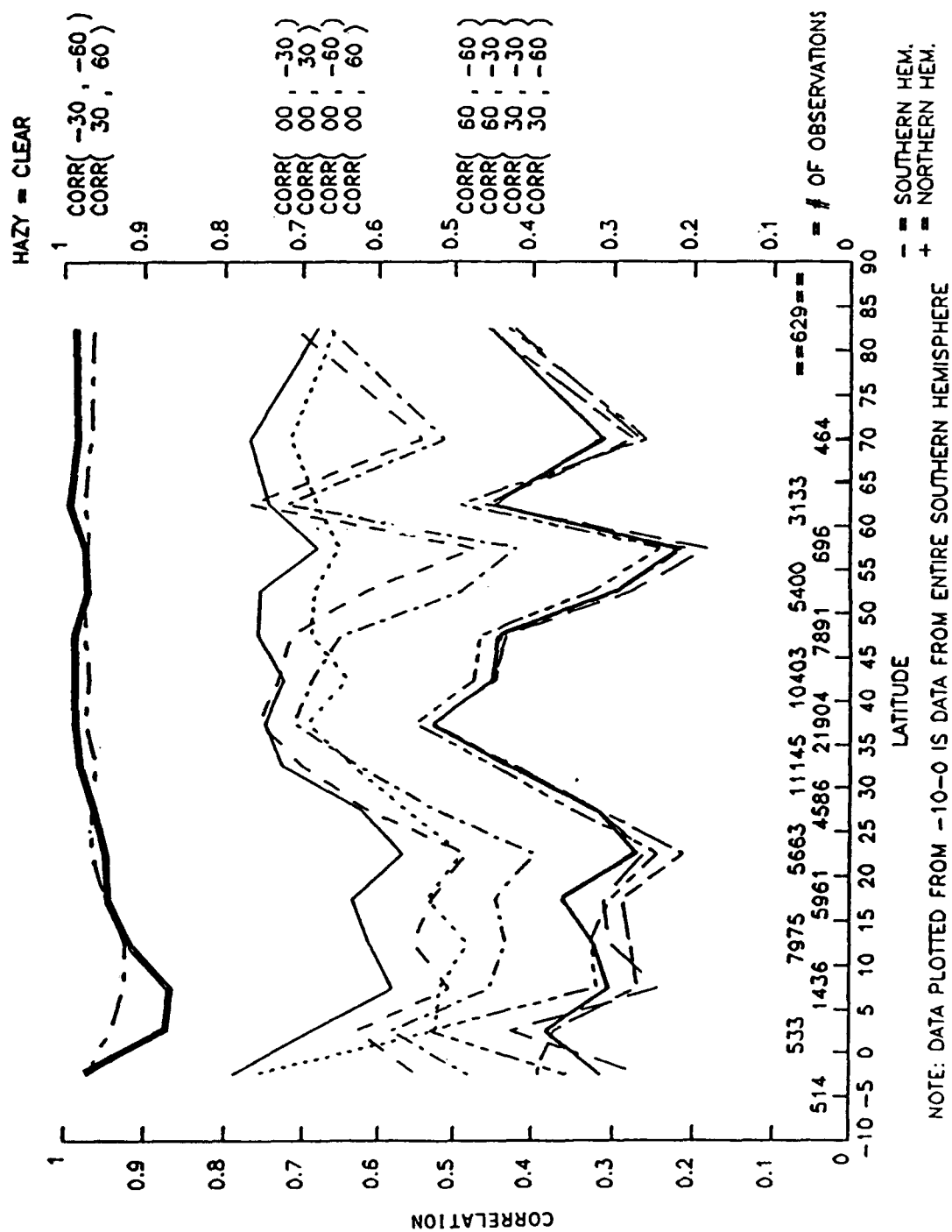


Figure 17. Correlation Between LOS Conditions at Indicated Angles for Various Latitudes. Hazy Is Considered Clear.  
(Altitudes  $\leq 10,000$  ft)

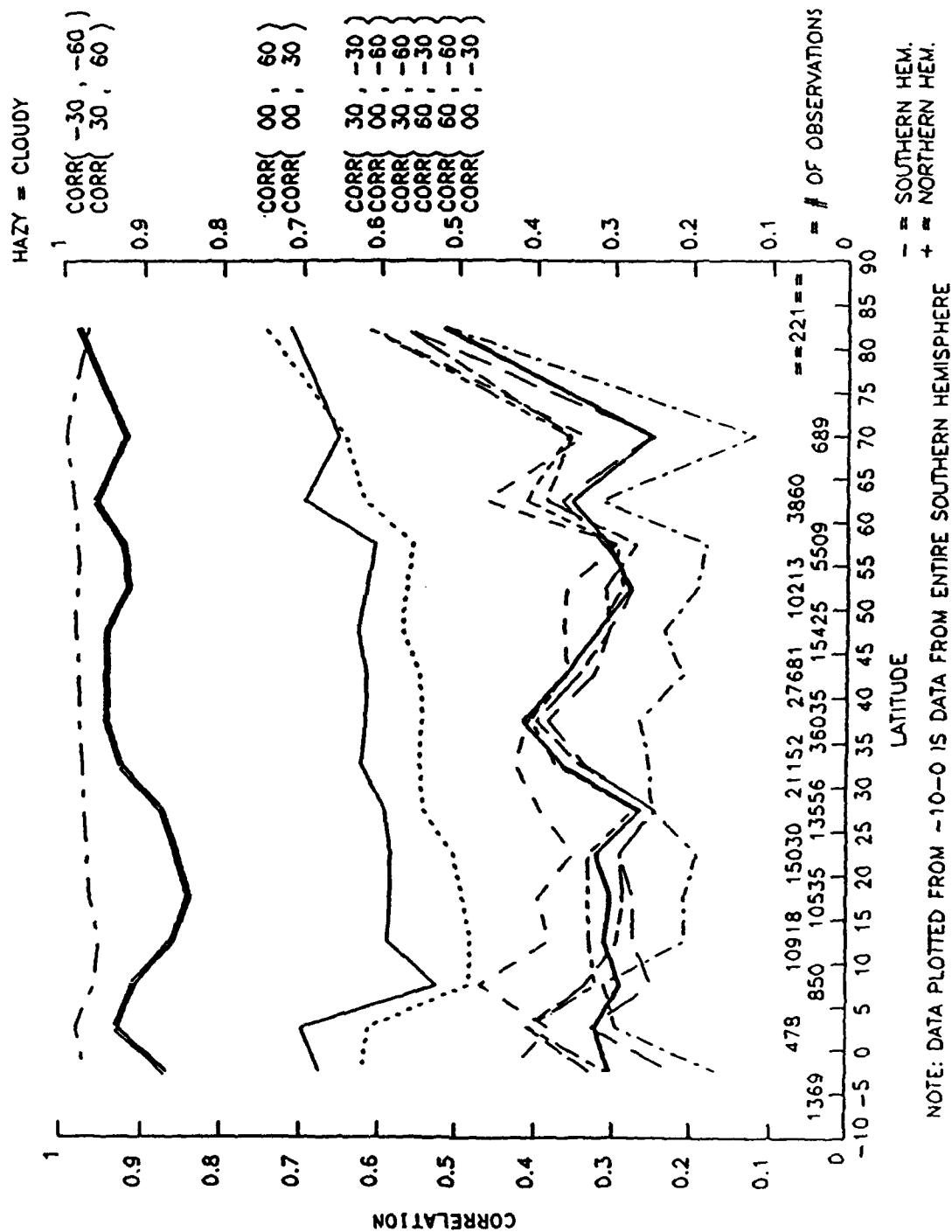


Figure 18. Correlation Between LOS Conditions at Indicated Angles for Various Latitudes. Hazy Is Considered Cloudy.  
(Altitudes >15,000 ft)



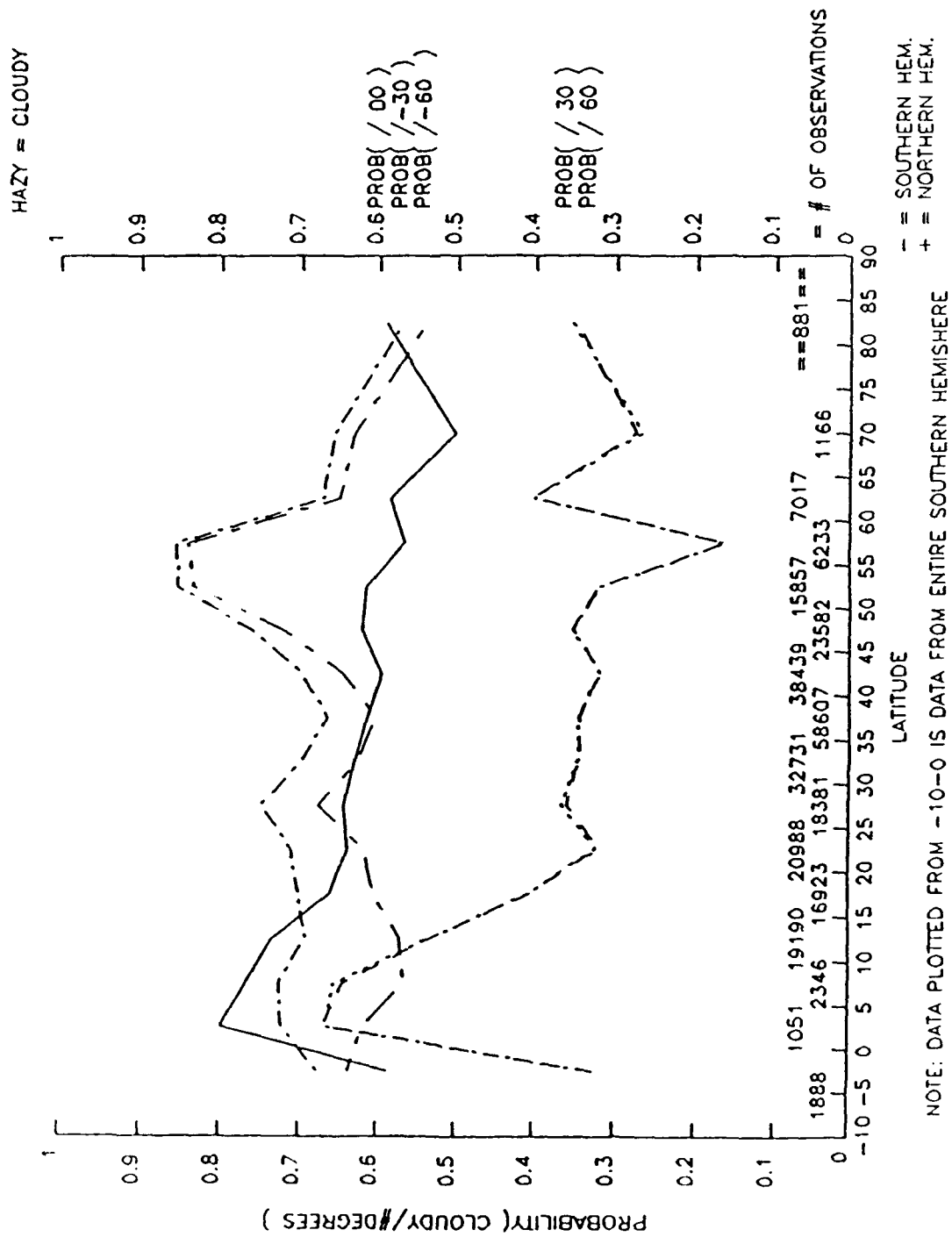


Figure 20. Probability of Cloudy LOS at Indicated Angles for Various Latitudes. Hazy Is Considered Cloudy. (All Altitudes)

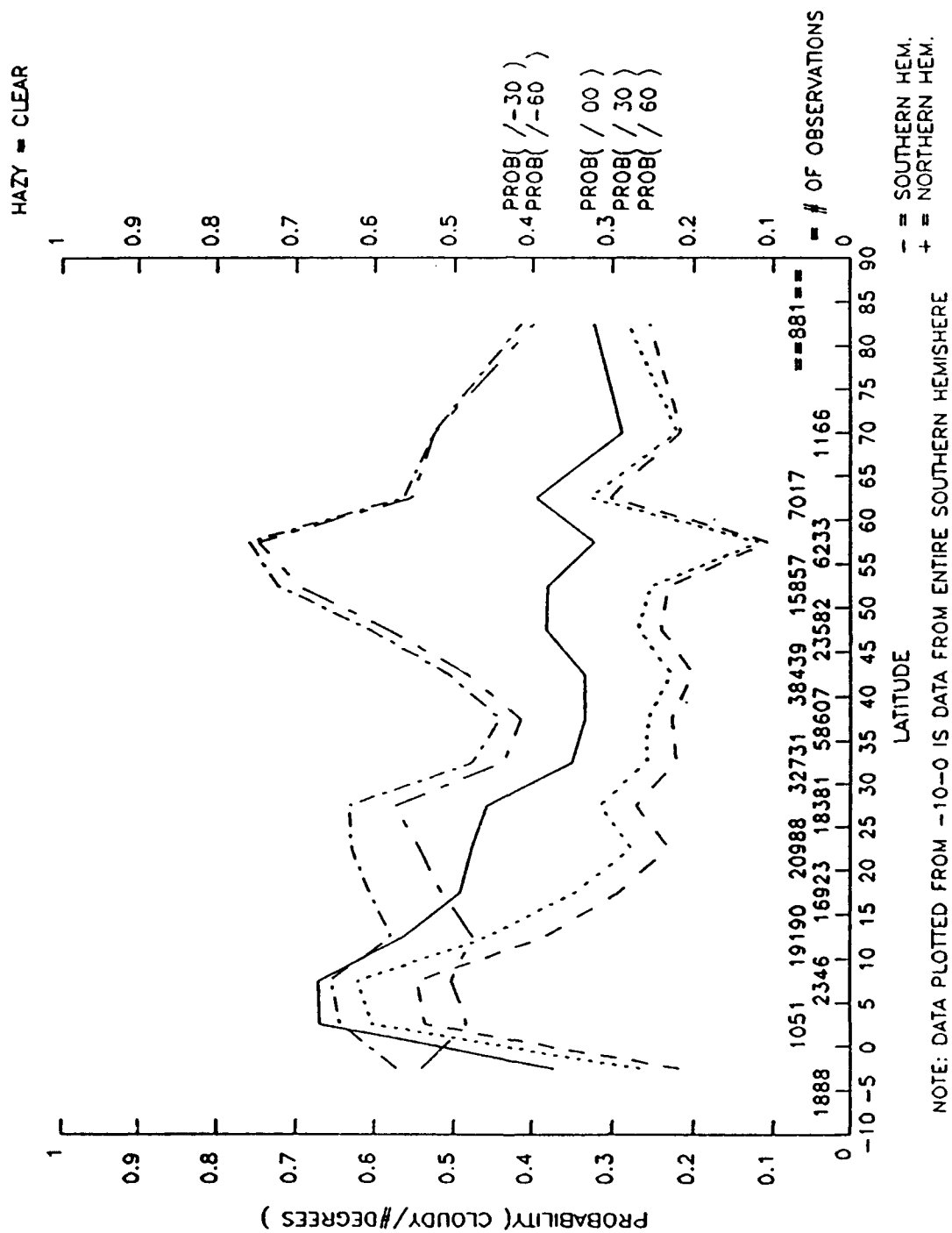


Figure 21. Probability of Cloudy I.O.S. at Indicated Angles for Various Latitudes. Hazy Is Considered Clear. (All Altitudes)

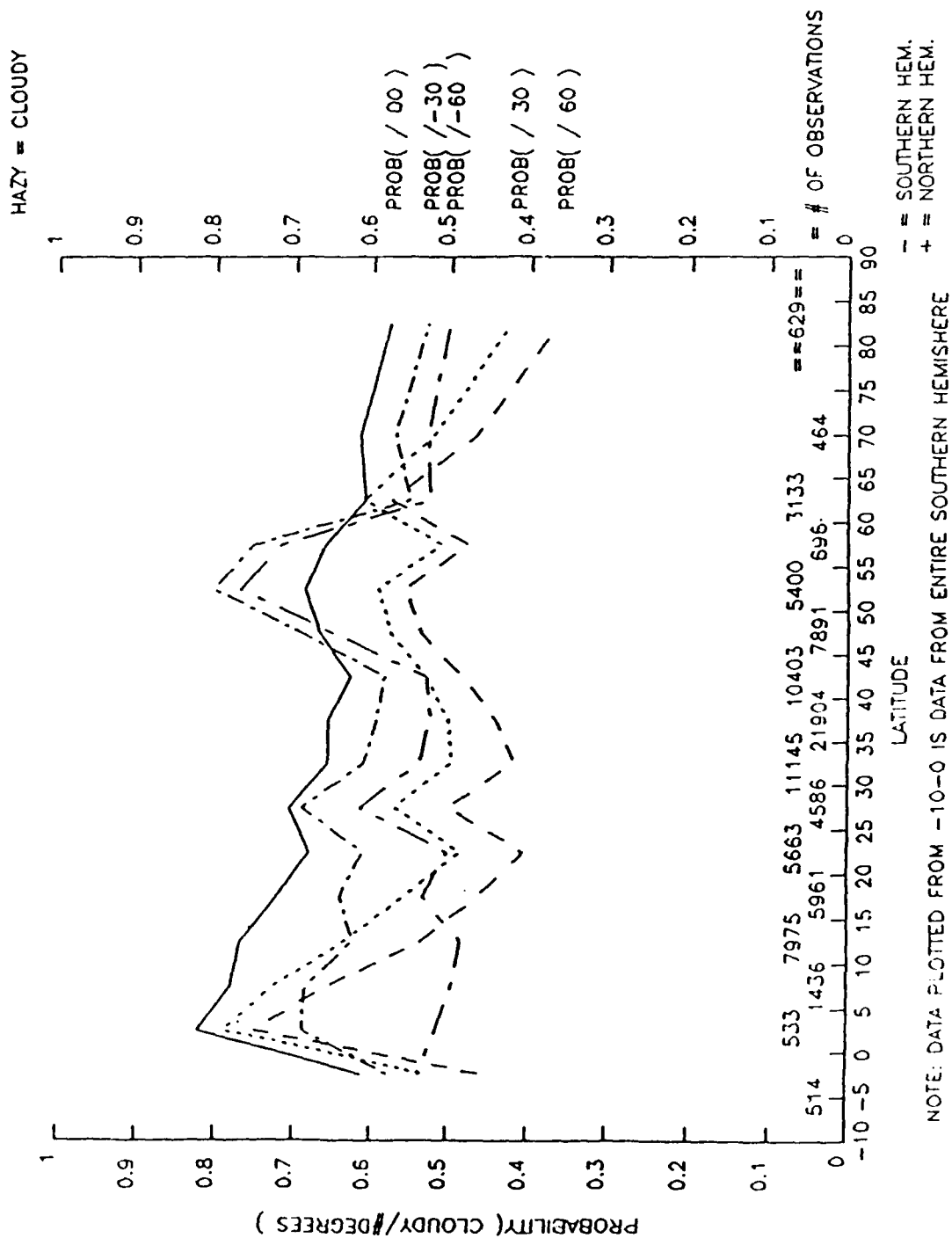


Figure 22. Probability of Cloudy LOS at Indicated Angles for Various Latitudes. Hazy Is Considered Cloudy. (Altitudes  $\leq 10,000$  ft)

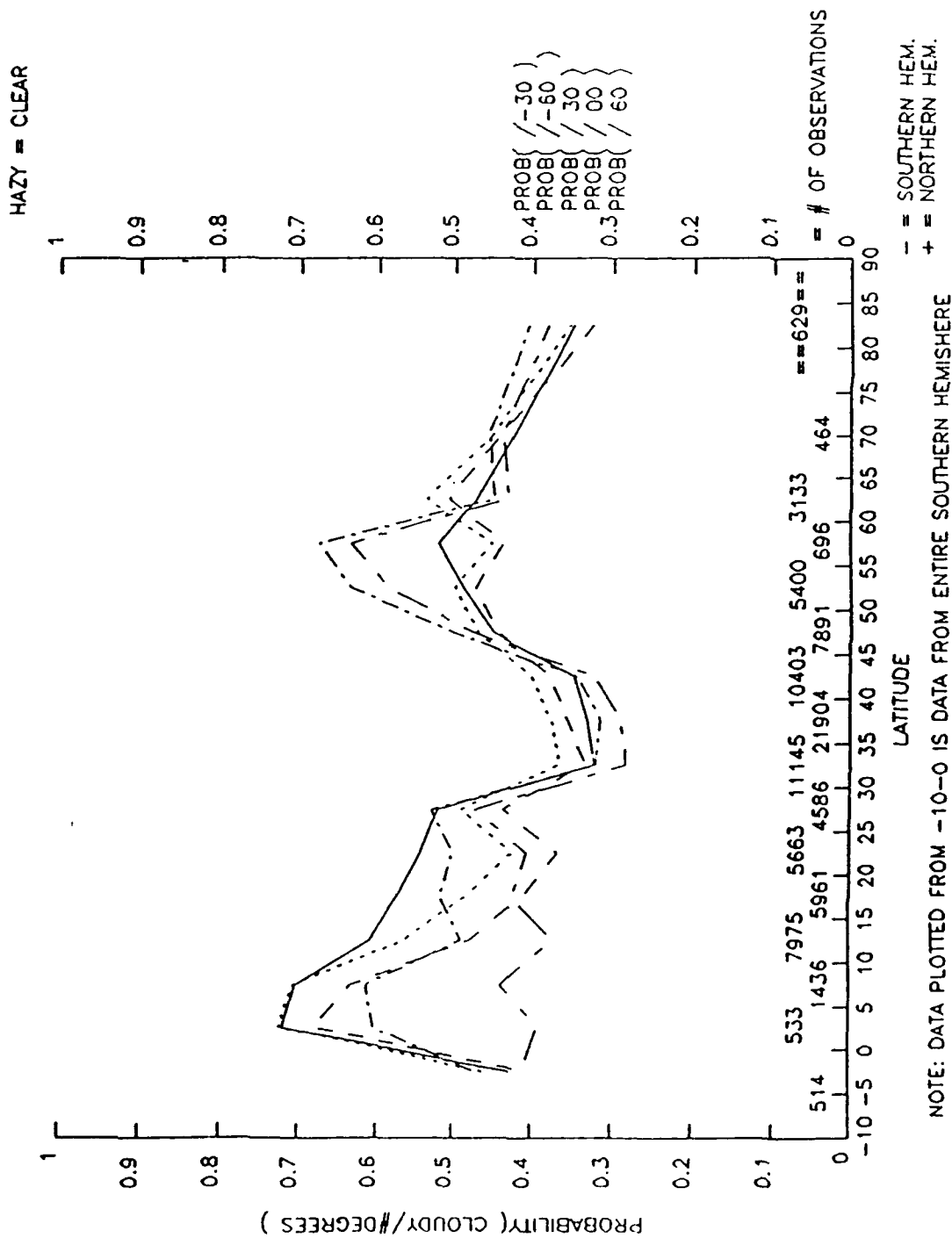


Figure 23. Probability of Cloudy LOS at Indicated Angles for Various Latitudes. Hazy Is Considered Clear. (Altitudes  $\leq 10,000$  ft)



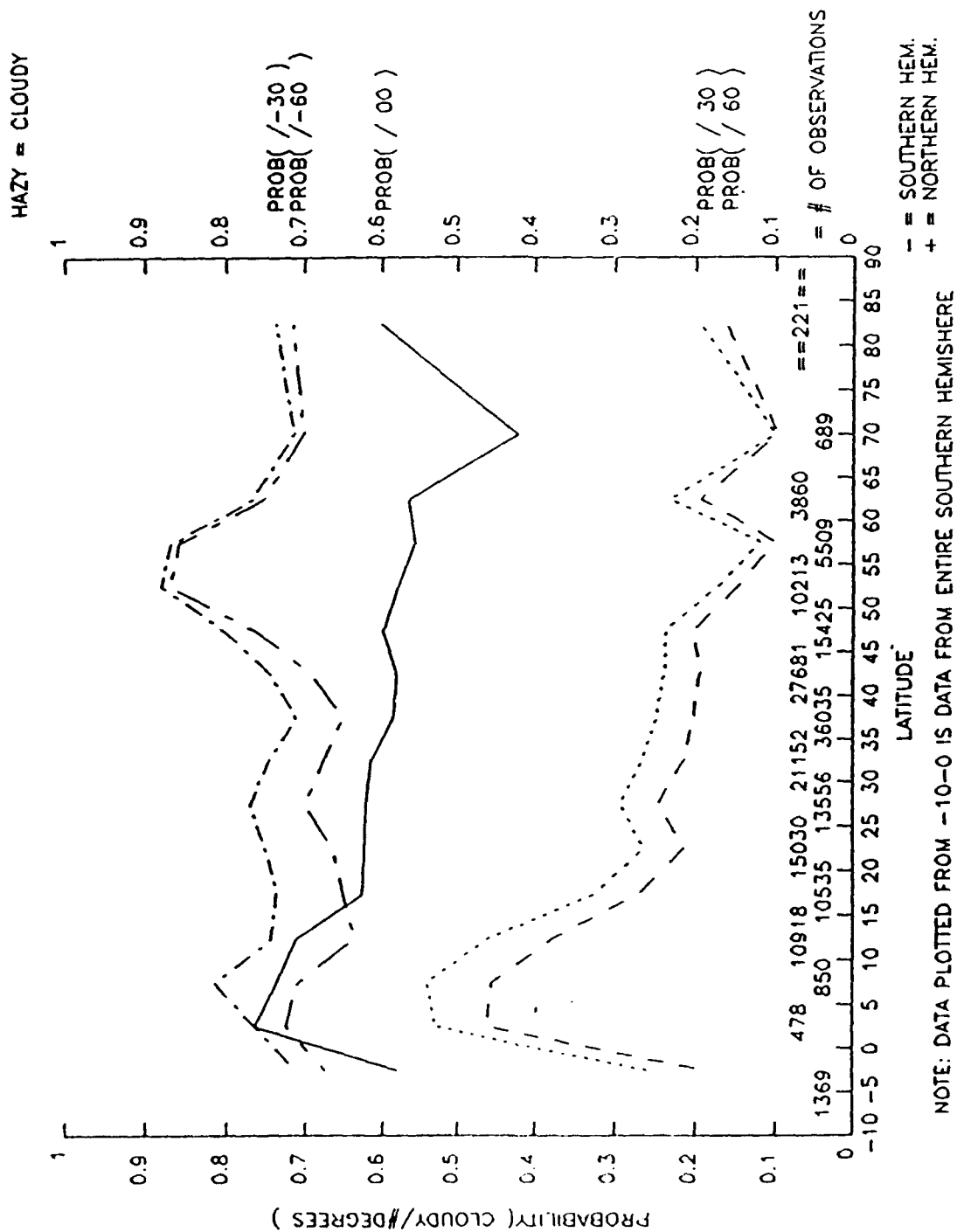


Figure 24. Probability of Cloudy LOS at Indicated Angles for Various Latitudes. Hazy Is Considered Cloudy. (Altitudes >15,000 ft)

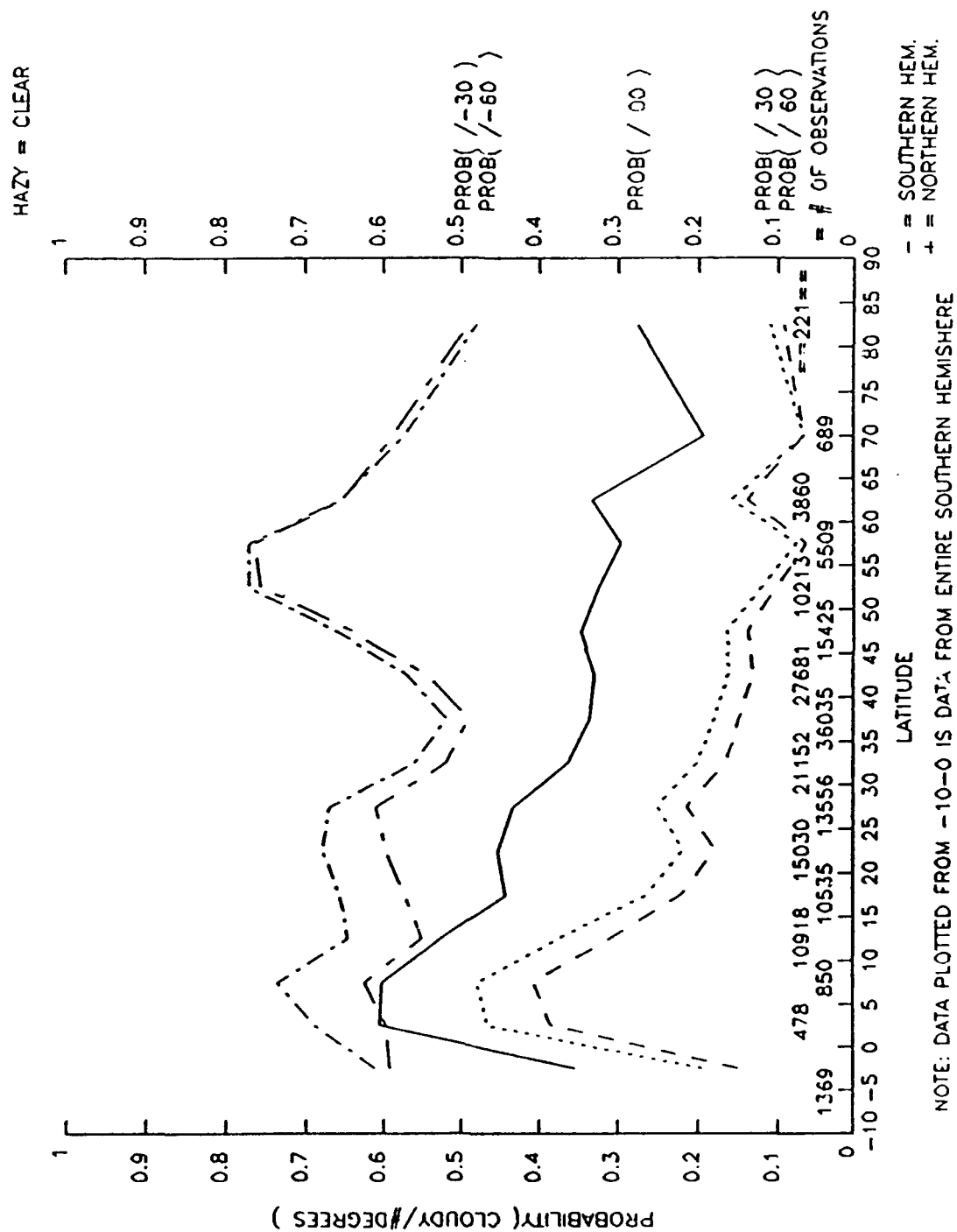


Figure 25. Probability of Cloudy LOS at Indicated Angles for Various Latitudes. Hazy Is Considered Clear. (Altitudes >15,000 ft)

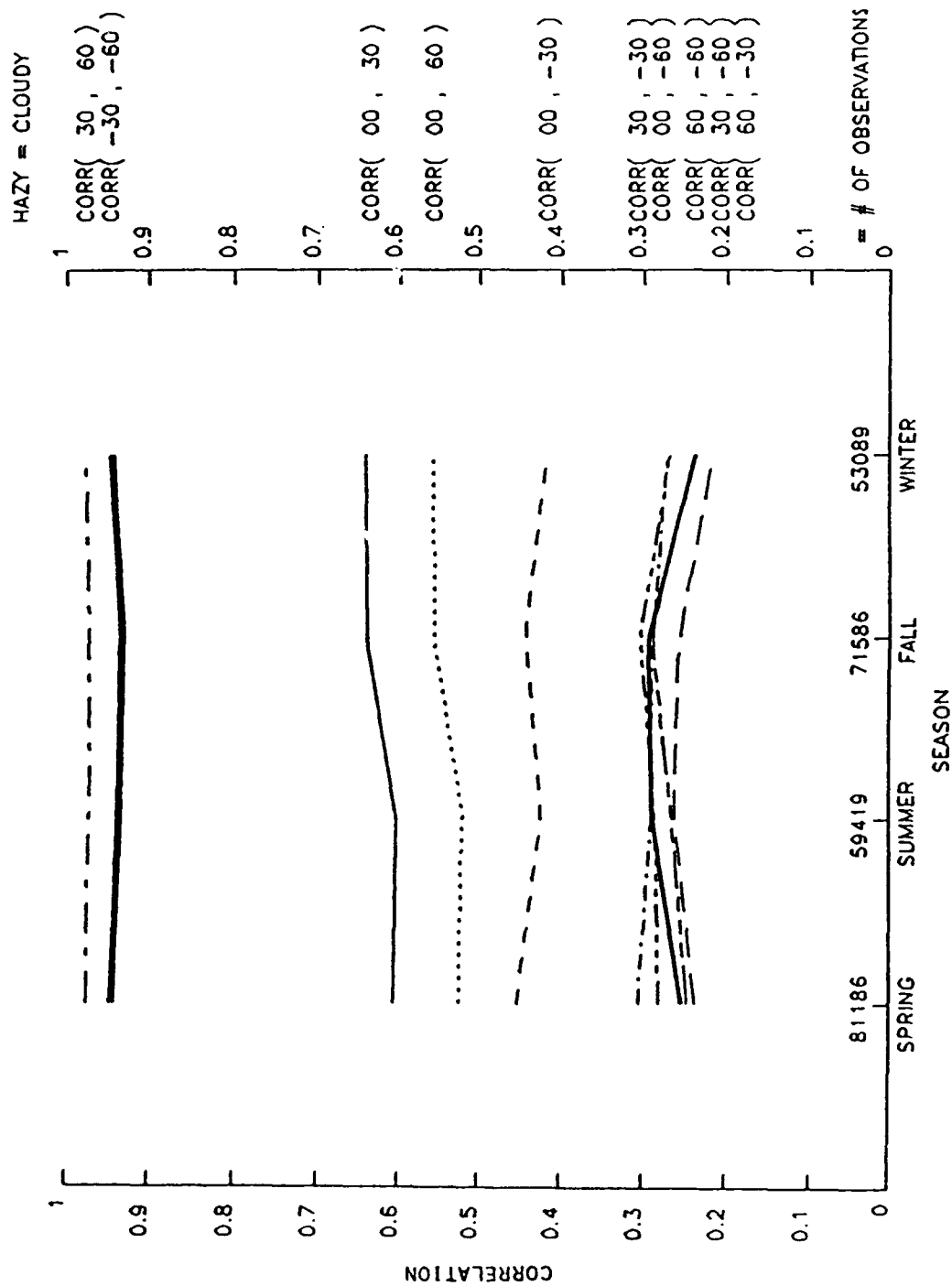


Figure 26. Correlation Between LOS Conditions at Indicated Angles for Seasons. Hazy Is Considered Cloudy. (All Latitudes)

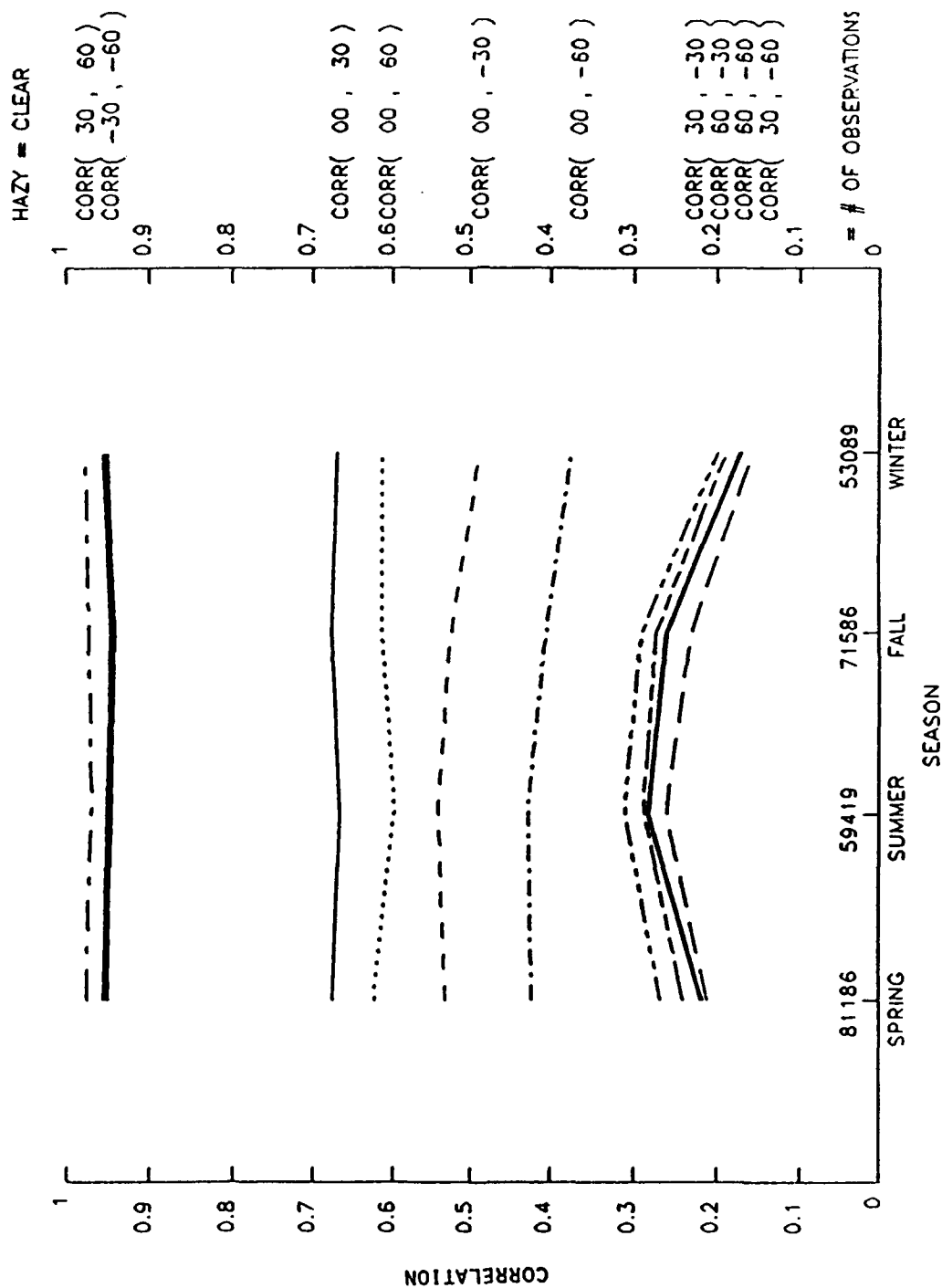


Figure 27. Correlation Between LOS Conditions at Indicated Angles for Seasons. Hazy Is Considered Clear. (All Latitudes)

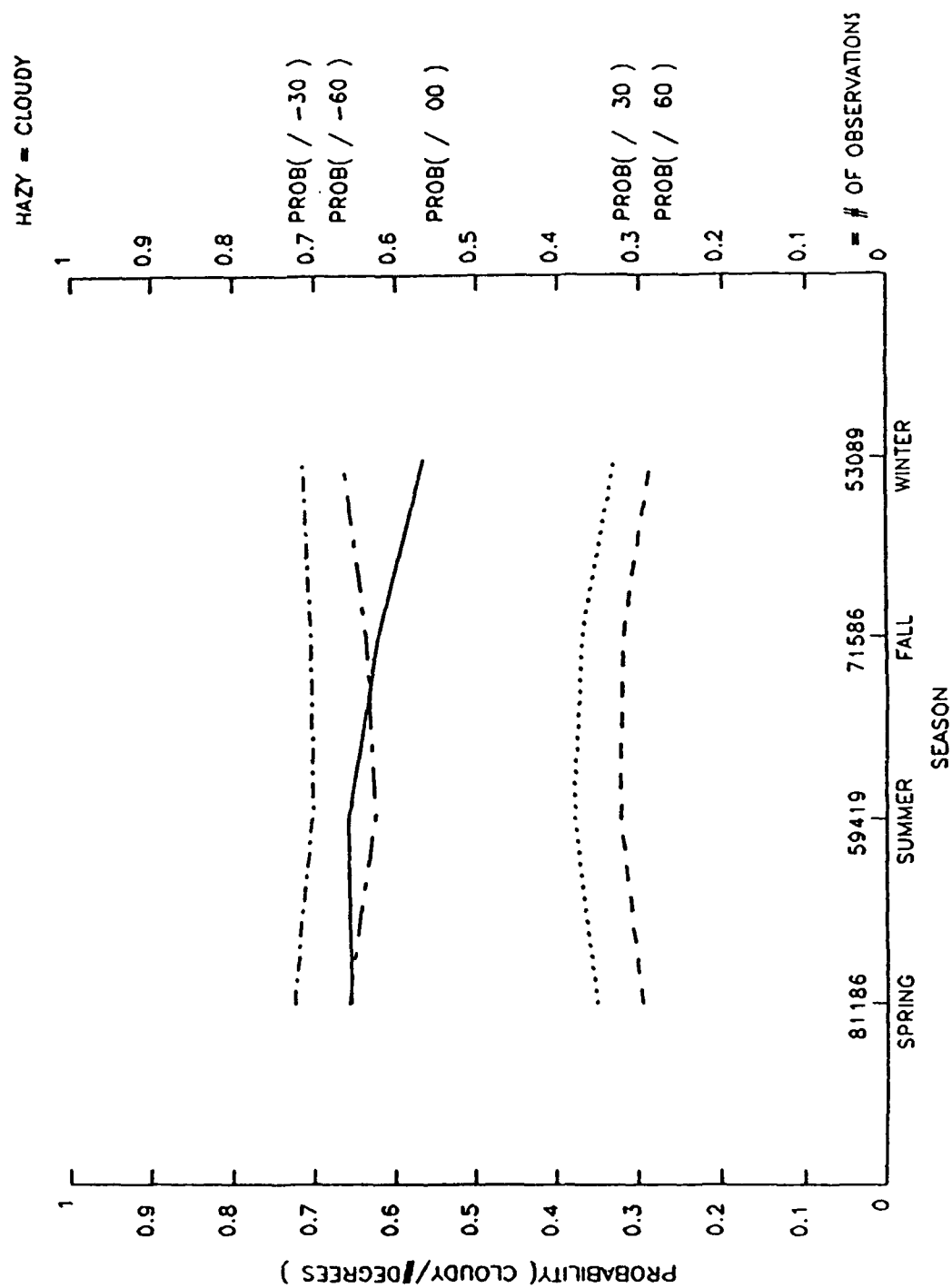


Figure 28. Probability of Cloudy LOS at Indicated Angles for Seasons. Hazy Is Considered Cloudy. (All Latitudes)

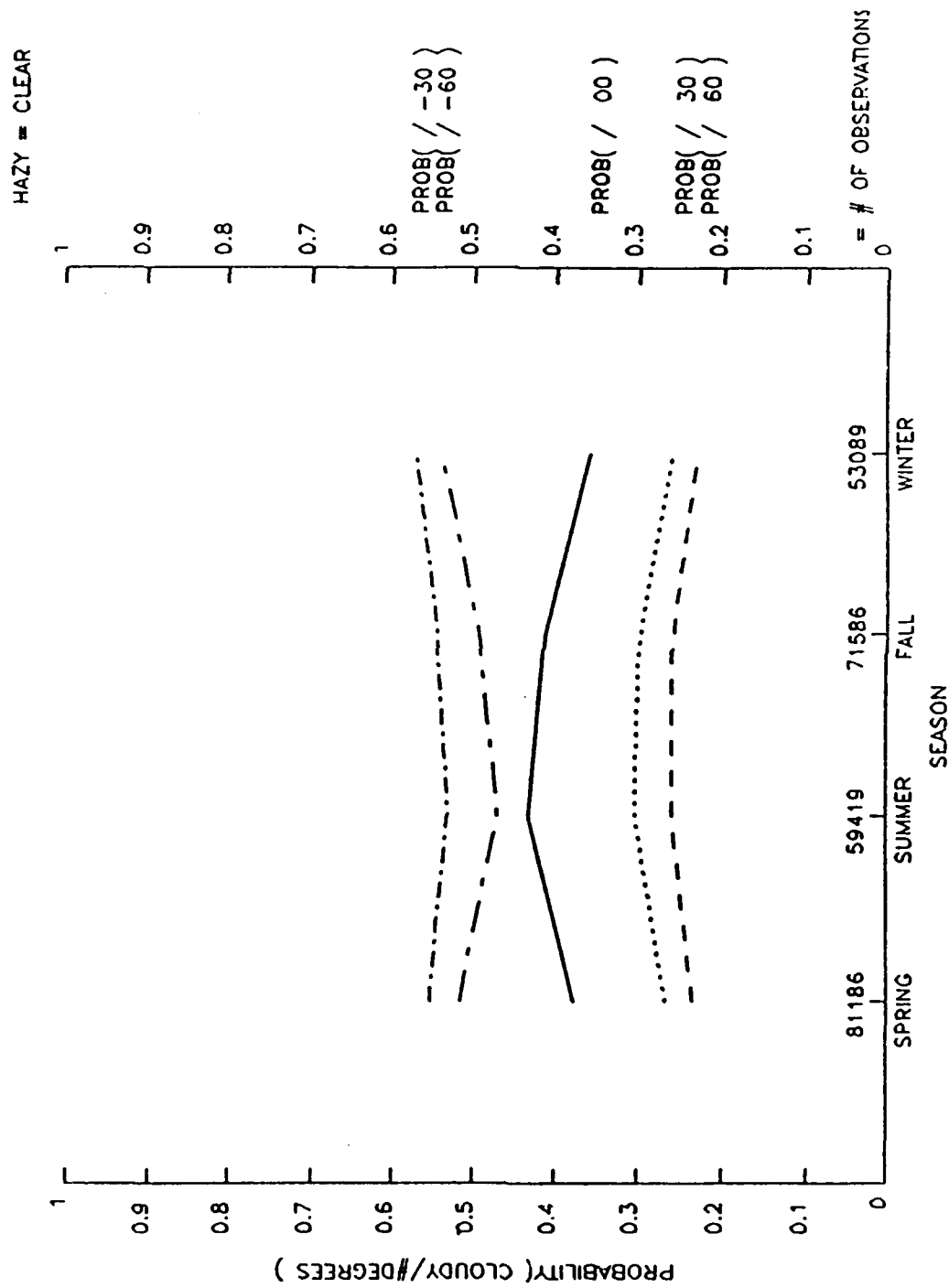


Figure 29. Probability of Cloudy LOS at Indicated Angles for Seasons. Hazy Is Considered Clear. (All Latitudes)

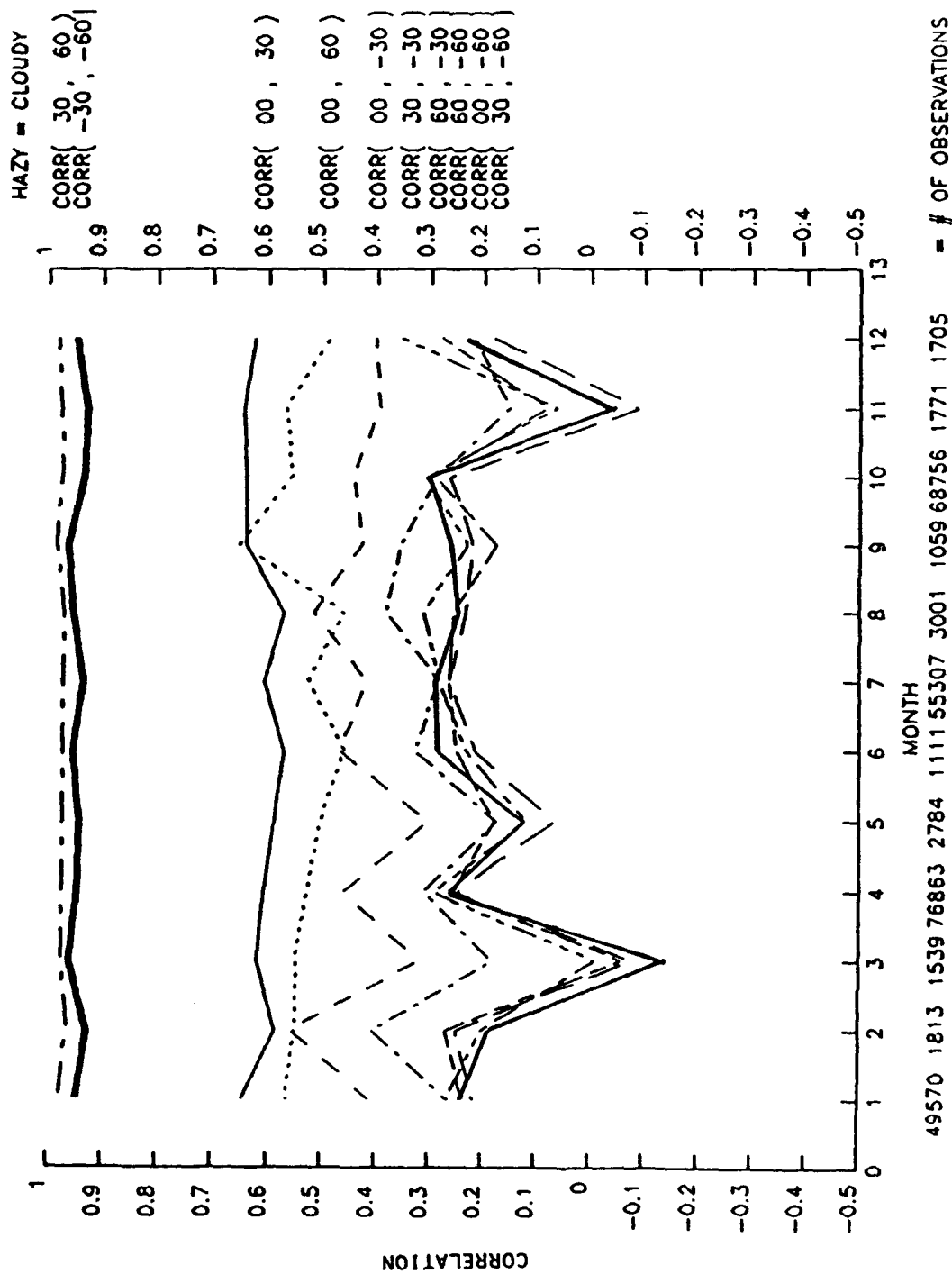


Figure 30. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Cloudy.  
(All Latitudes and Altitudes)

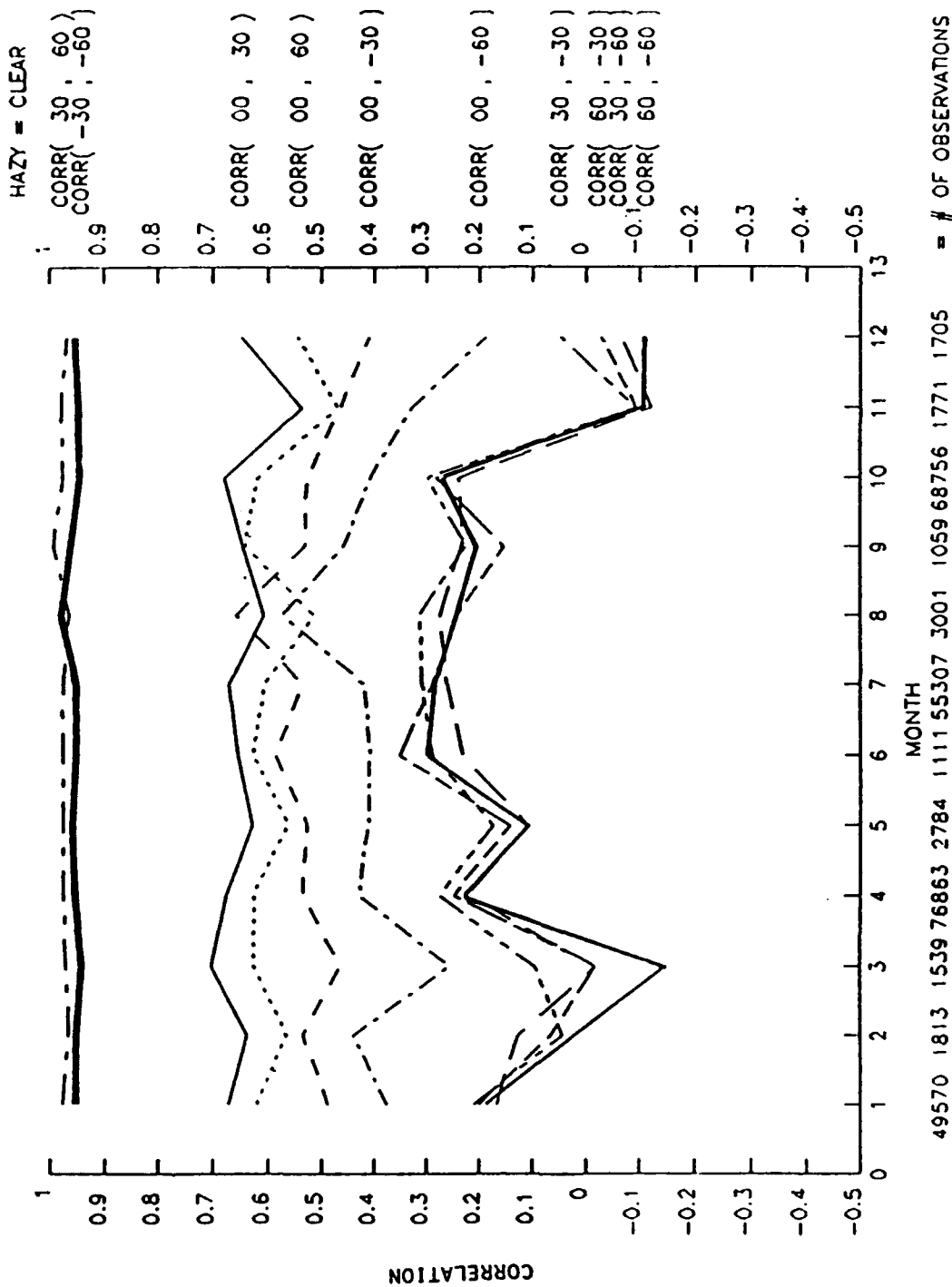


Figure 31. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Clear.  
(All Latitudes and Altitudes)



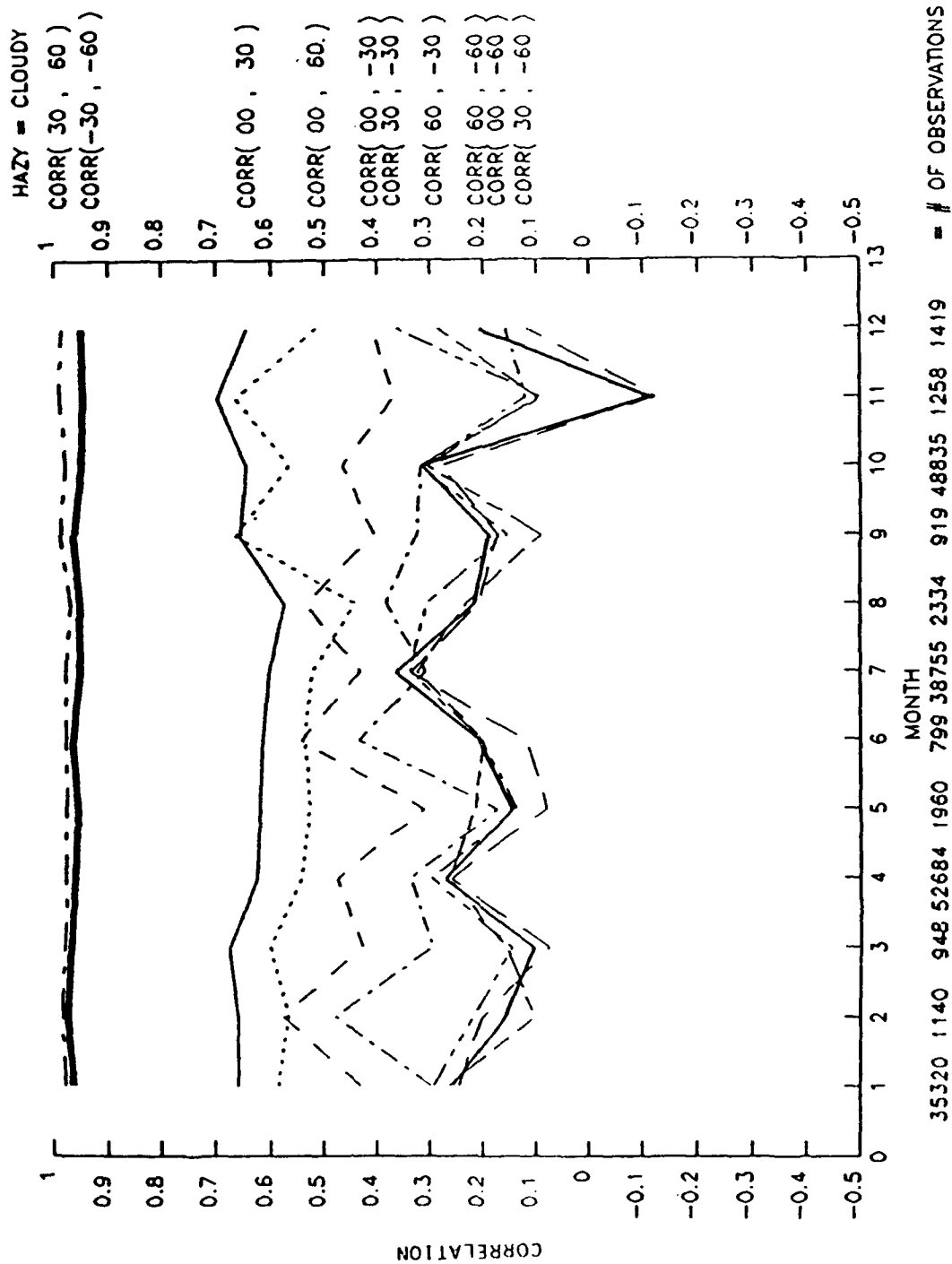


Figure 32. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Cloudy. (Latitudes  $\geq 30^\circ$  N)

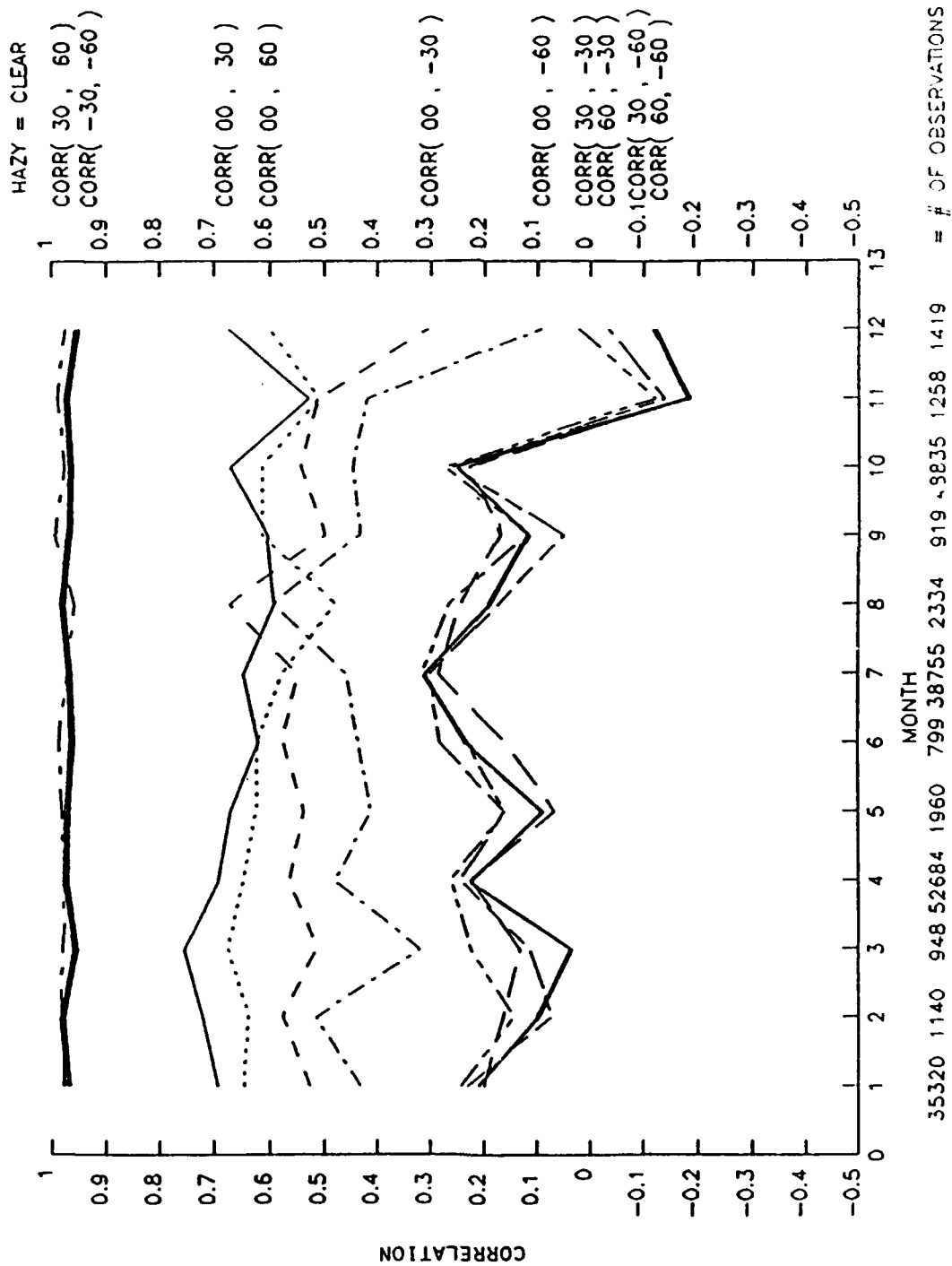


Figure 33. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Clear. (Latitudes  $\geq 30^\circ$  N)

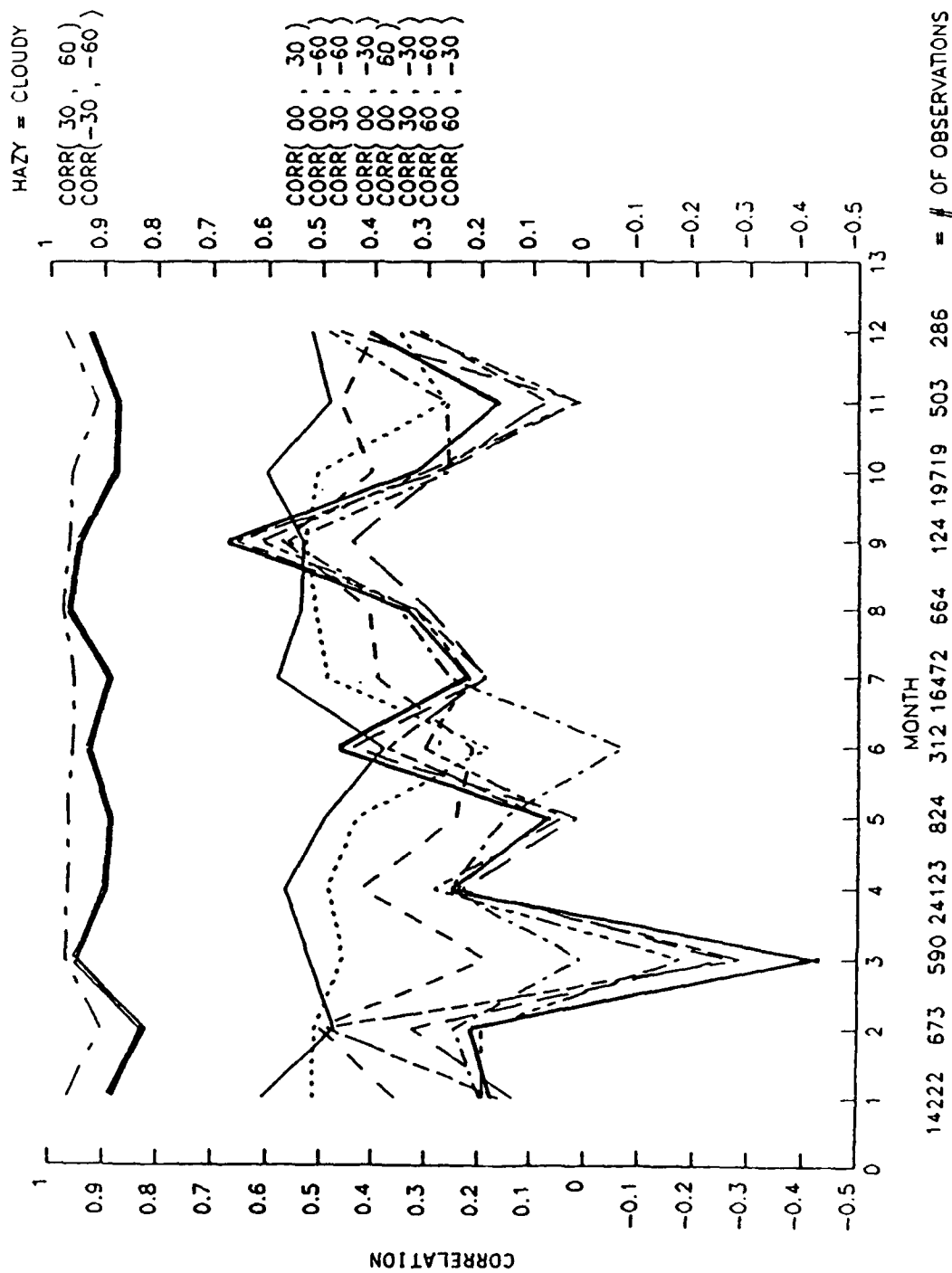


Figure 34. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Cloudy.  
( $30^{\circ}$  S < Latitudes <  $30^{\circ}$  N)

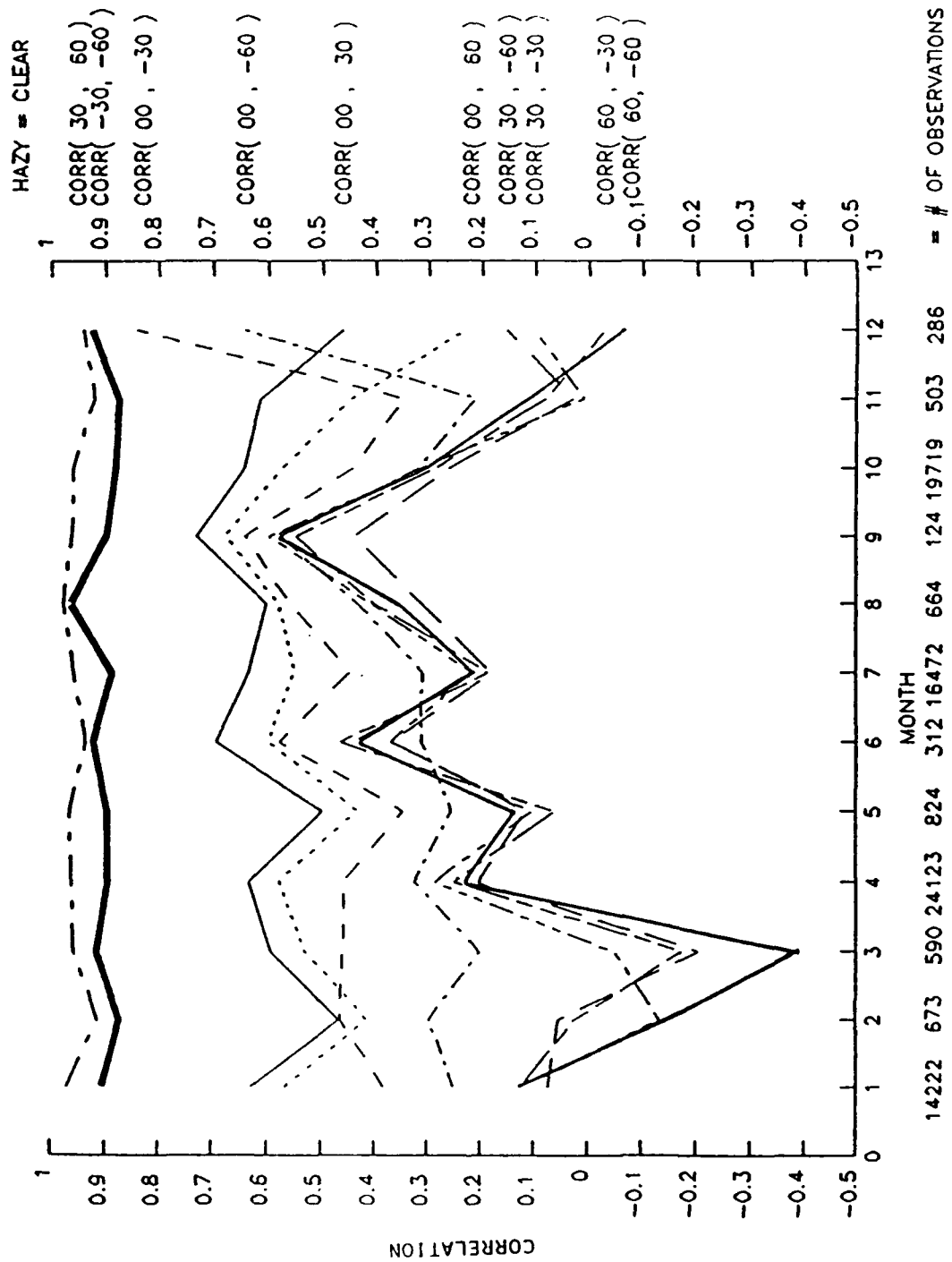


Figure 35. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Clear.  
(30° S < Latitudes < 30° N)

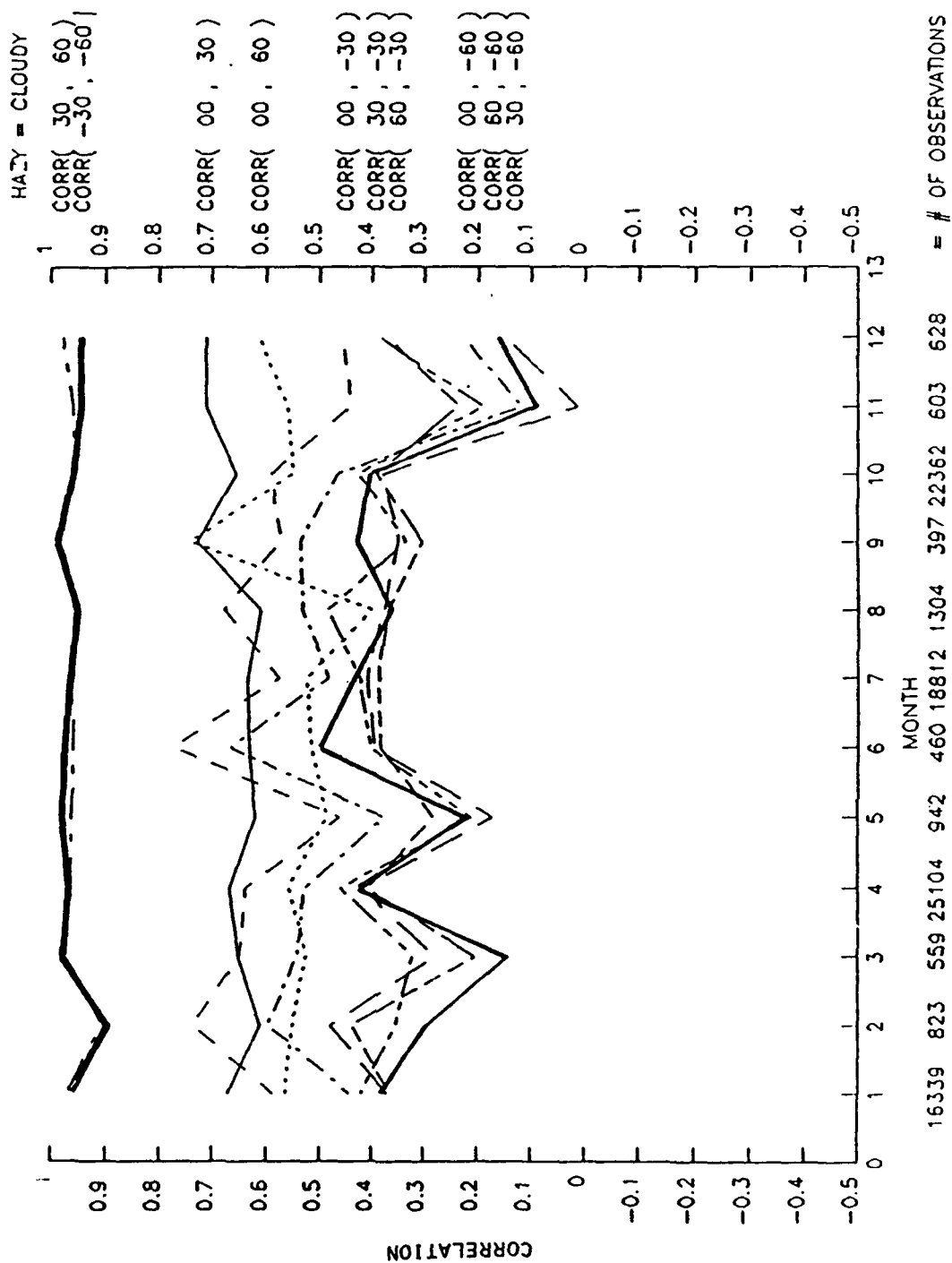


Figure 36. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Cloudy. (Altitude  $\leq 10,000$  ft)

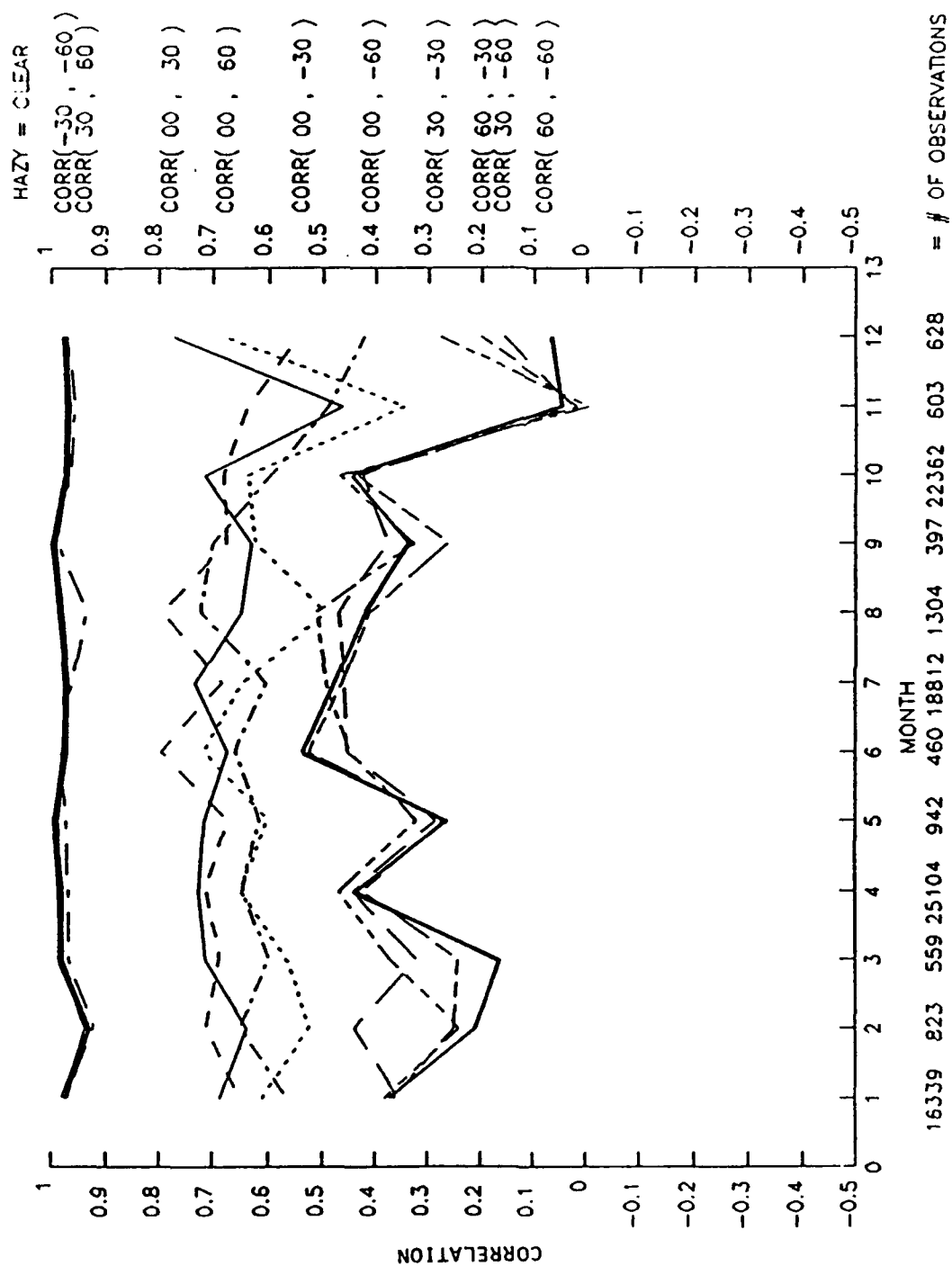


Figure 37. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Clear. (Altitude  $\leq 10,000$  ft)

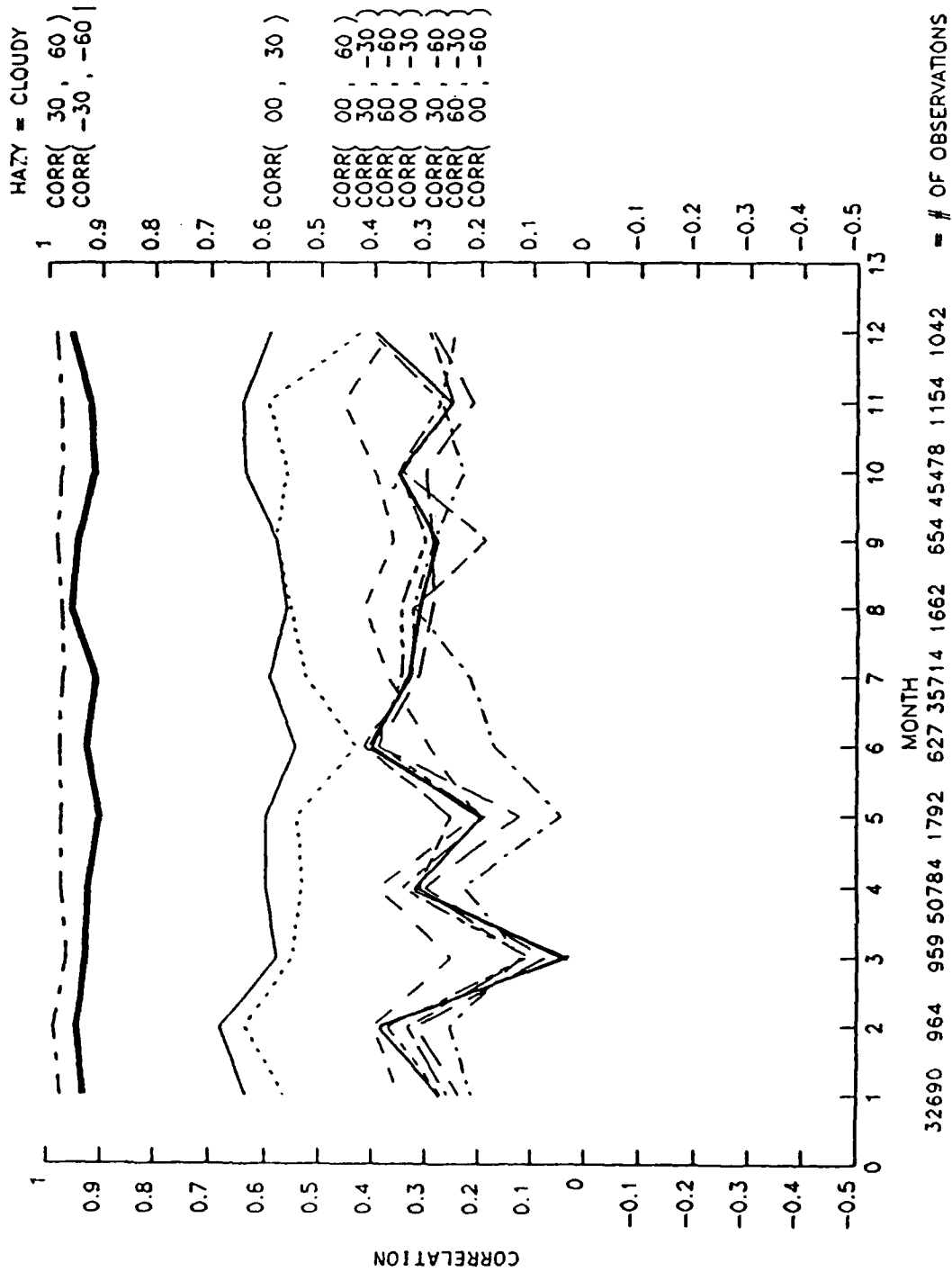


Figure 38. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Cloudy. (Altitude > 15,000 ft)

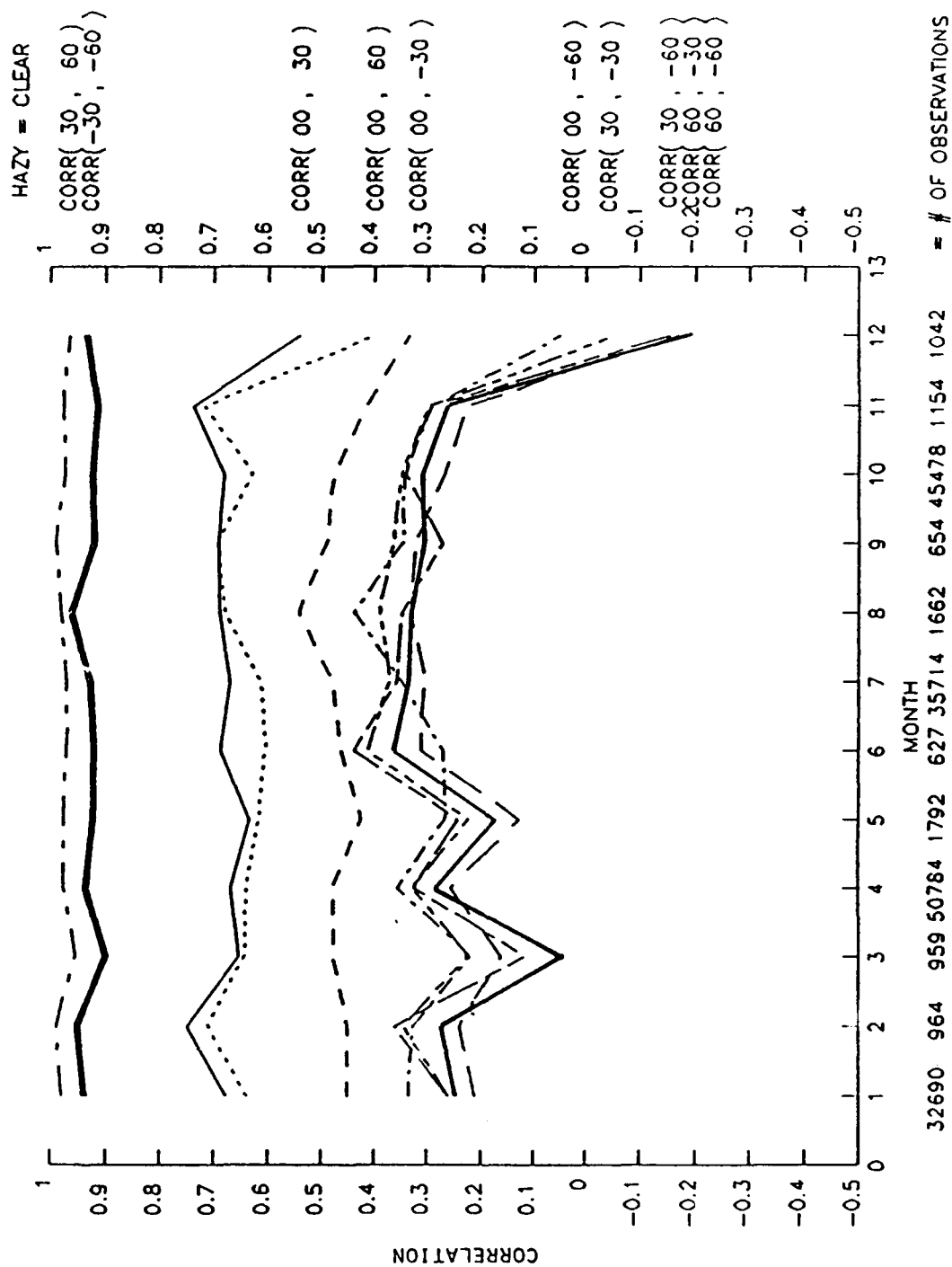


Figure 39. Correlation Between LOS Conditions at Indicated Angles for Months. Hazy Is Considered Clear. (Altitude > 15,000 ft)



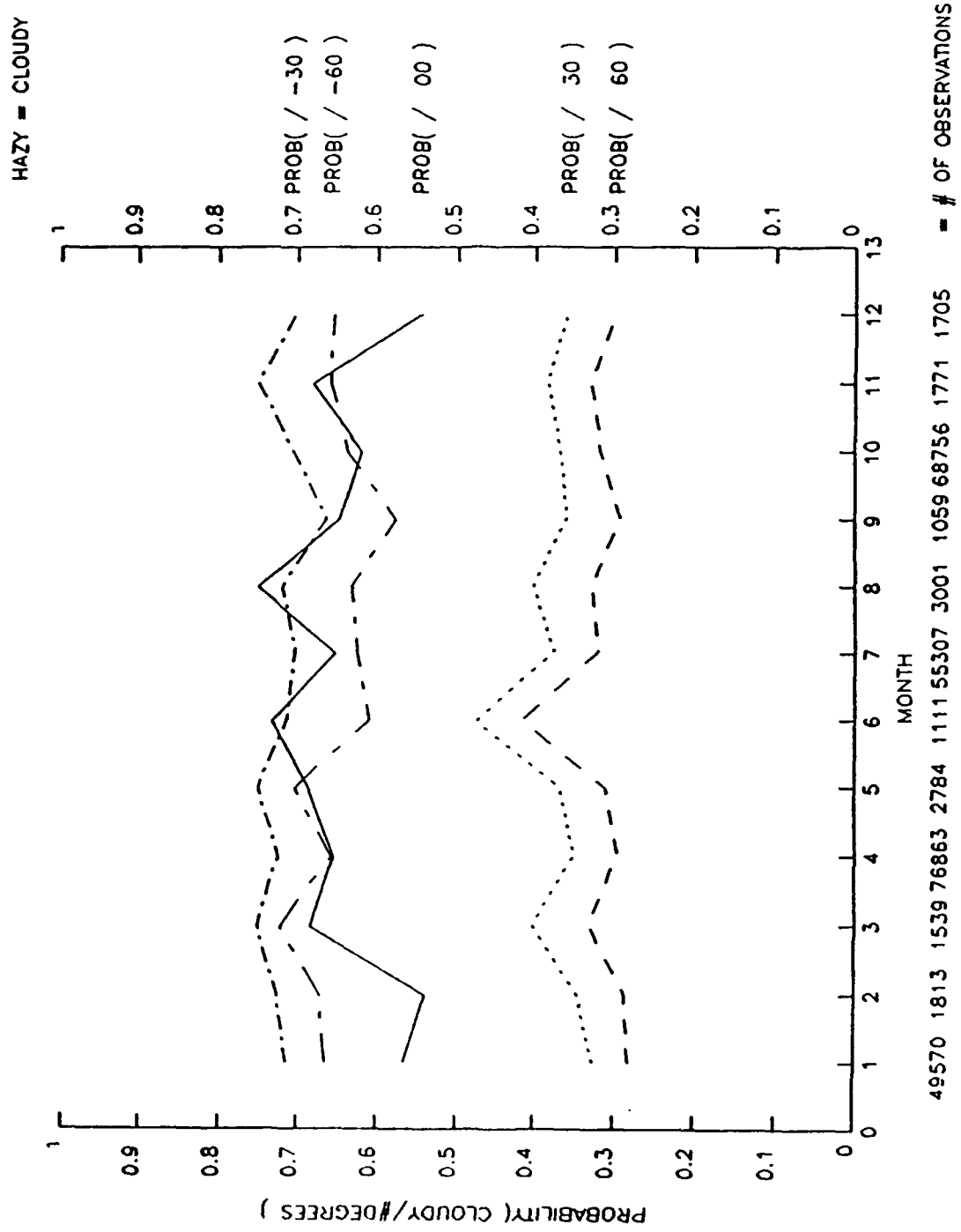


Figure 40. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Cloudy. (All Latitudes and Altitudes)

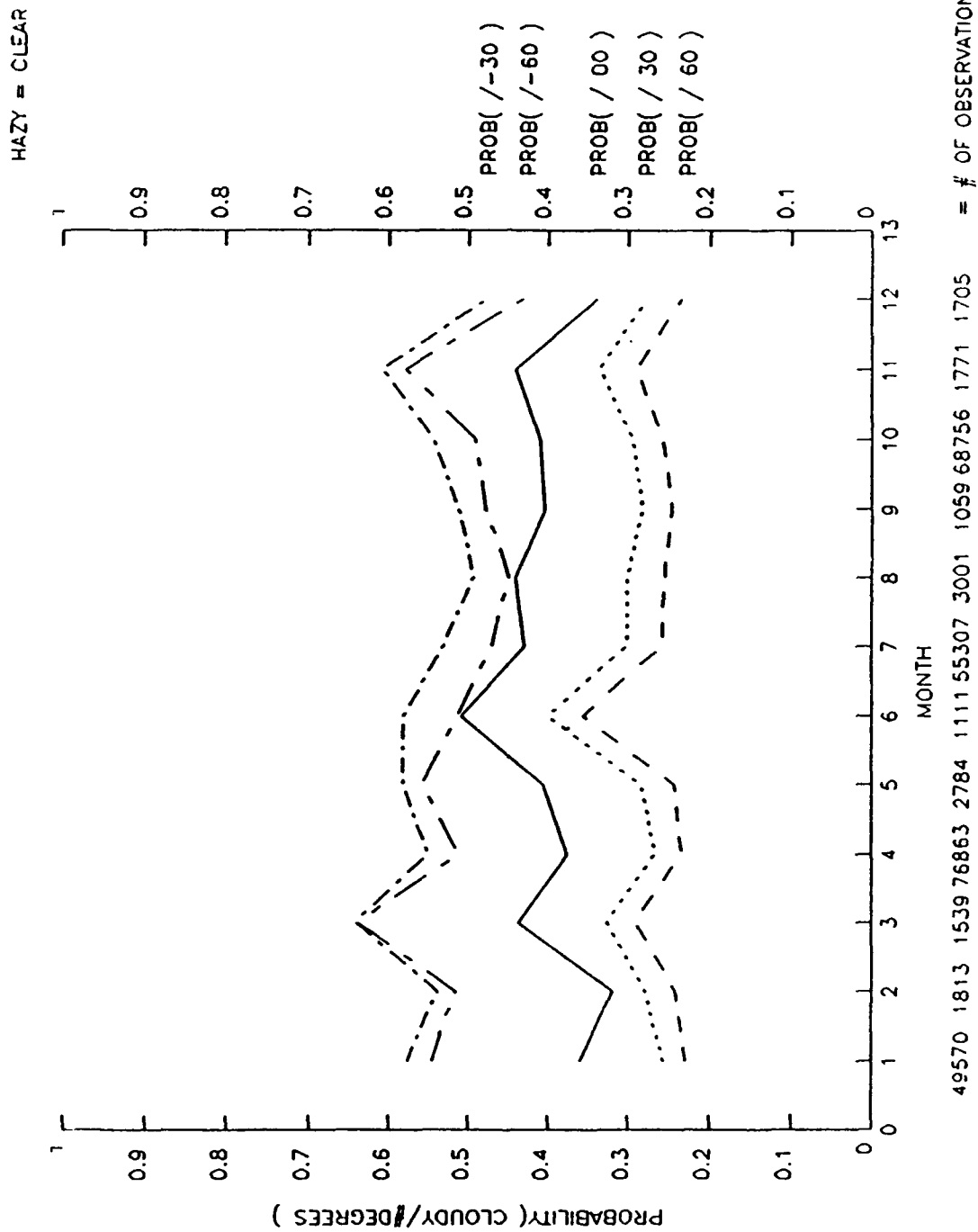


Figure 41. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Clear. (All Latitudes and Altitudes)

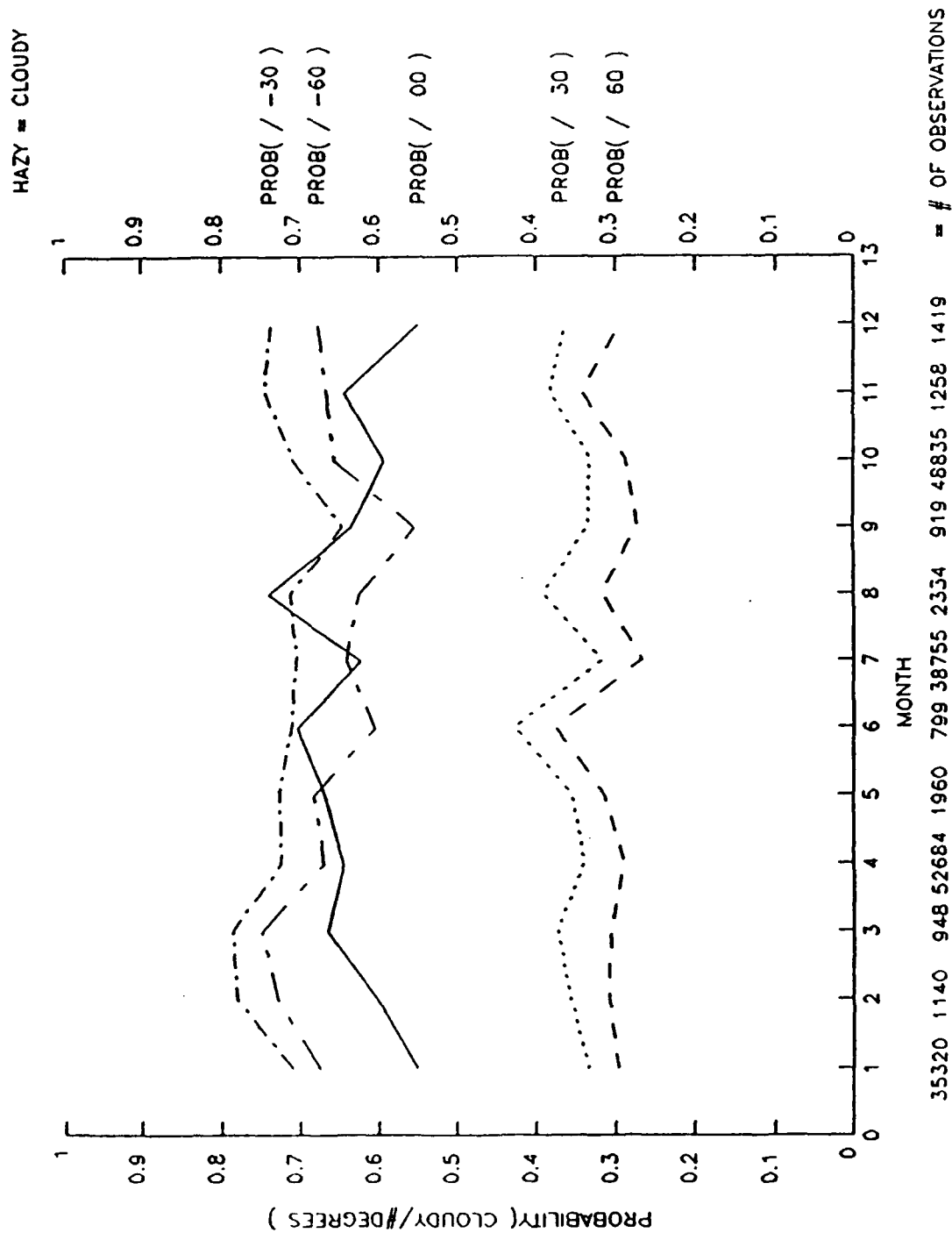


Figure 42. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Cloudy. (Latitudes  $\geq 30^\circ$  N)

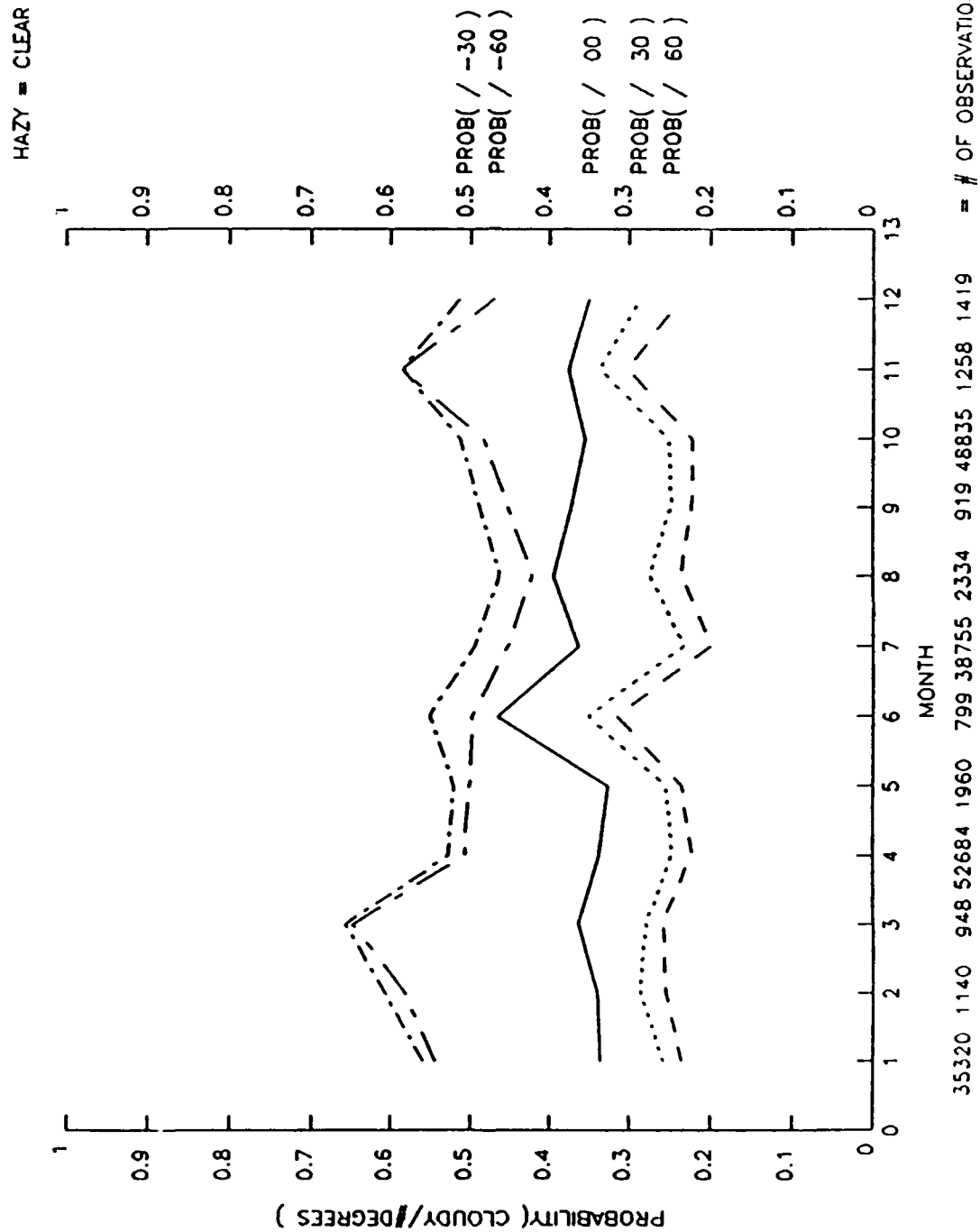


Figure 43. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Clear. (Latitudes  $\geq 30^\circ$  N)

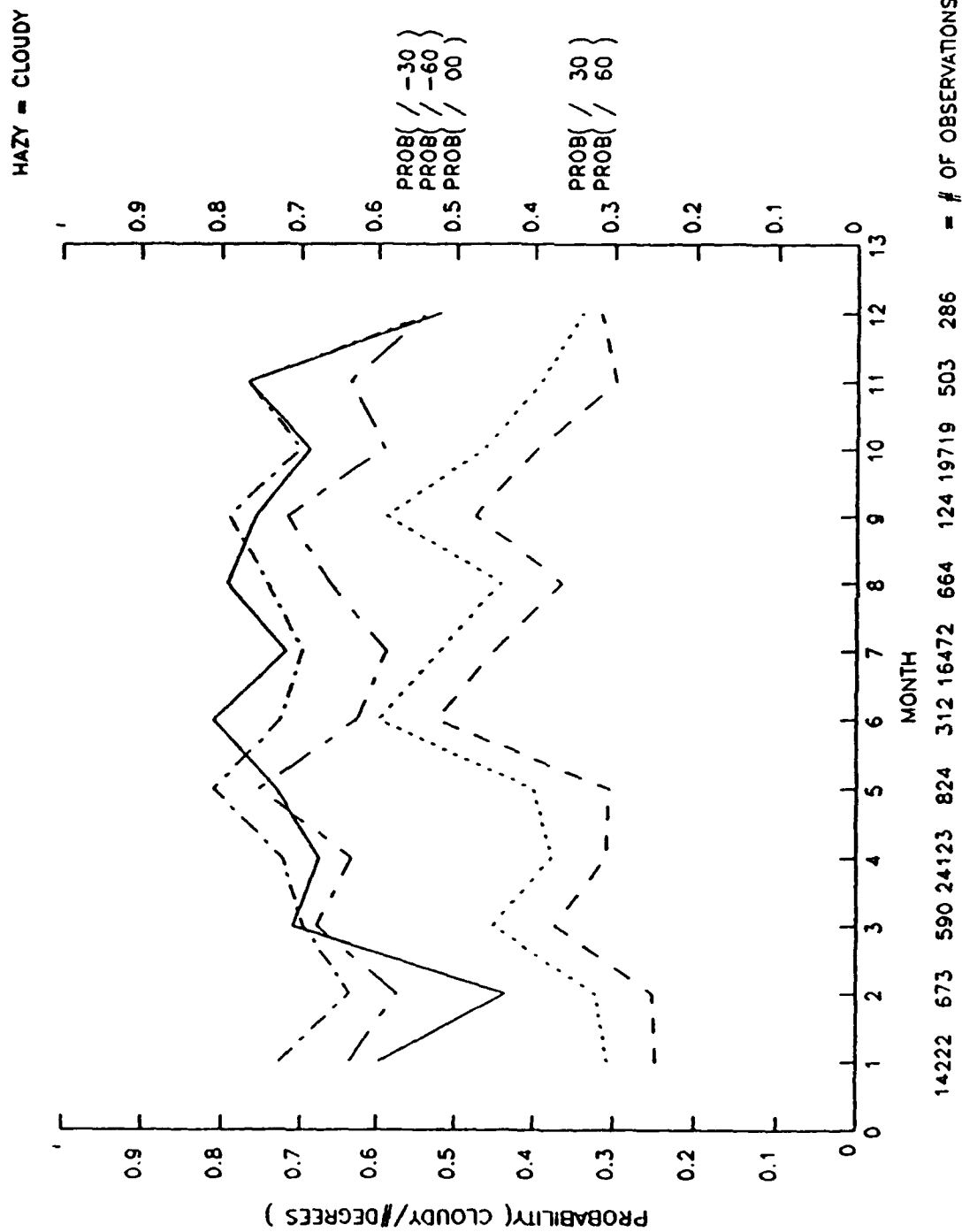


Figure 44. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Cloudy. ( $30^{\circ}$  S < Latitudes <  $30^{\circ}$  N)

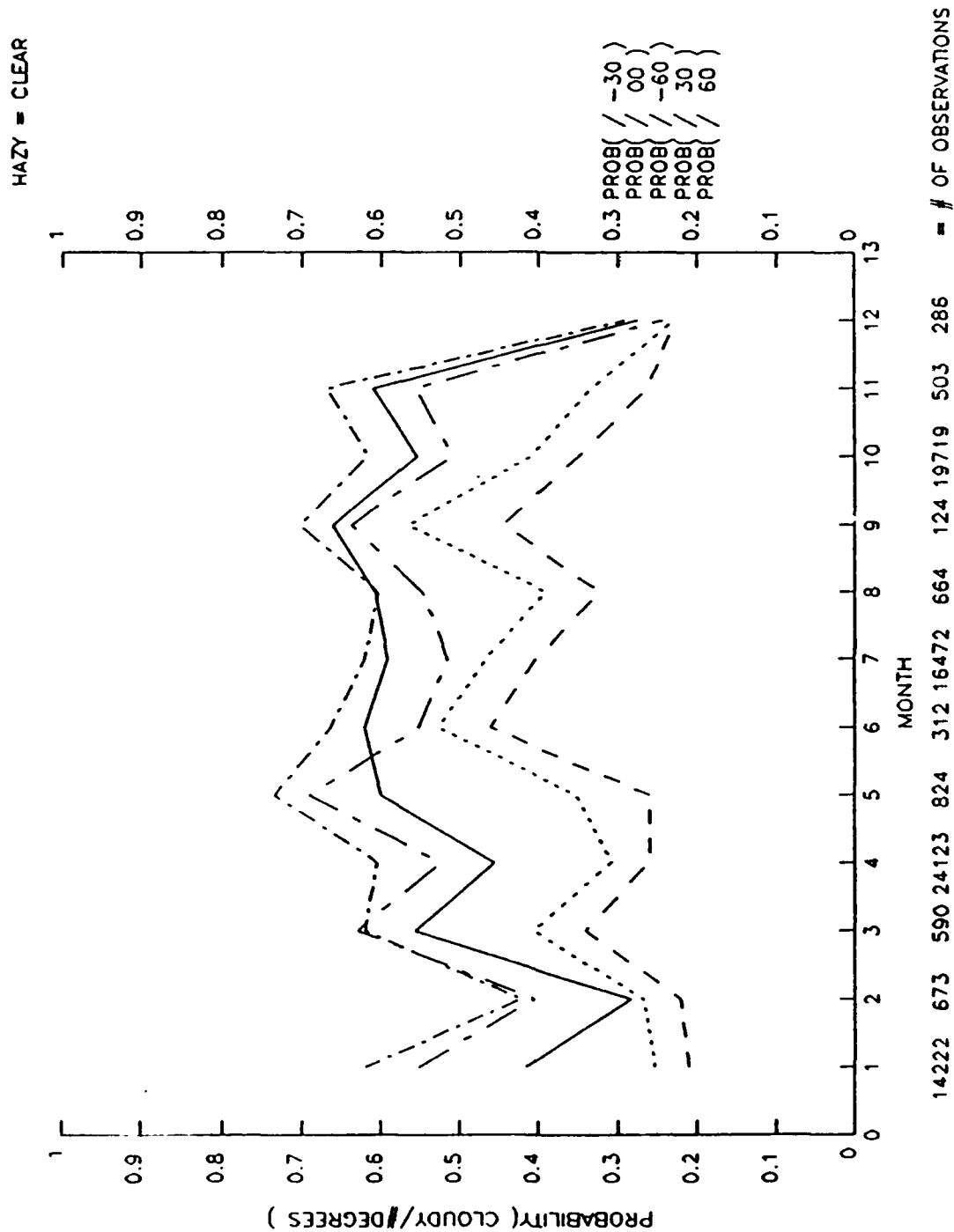


Figure 45. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Clear. ( $30^{\circ}$  S < Latitudes <  $30^{\circ}$  N)

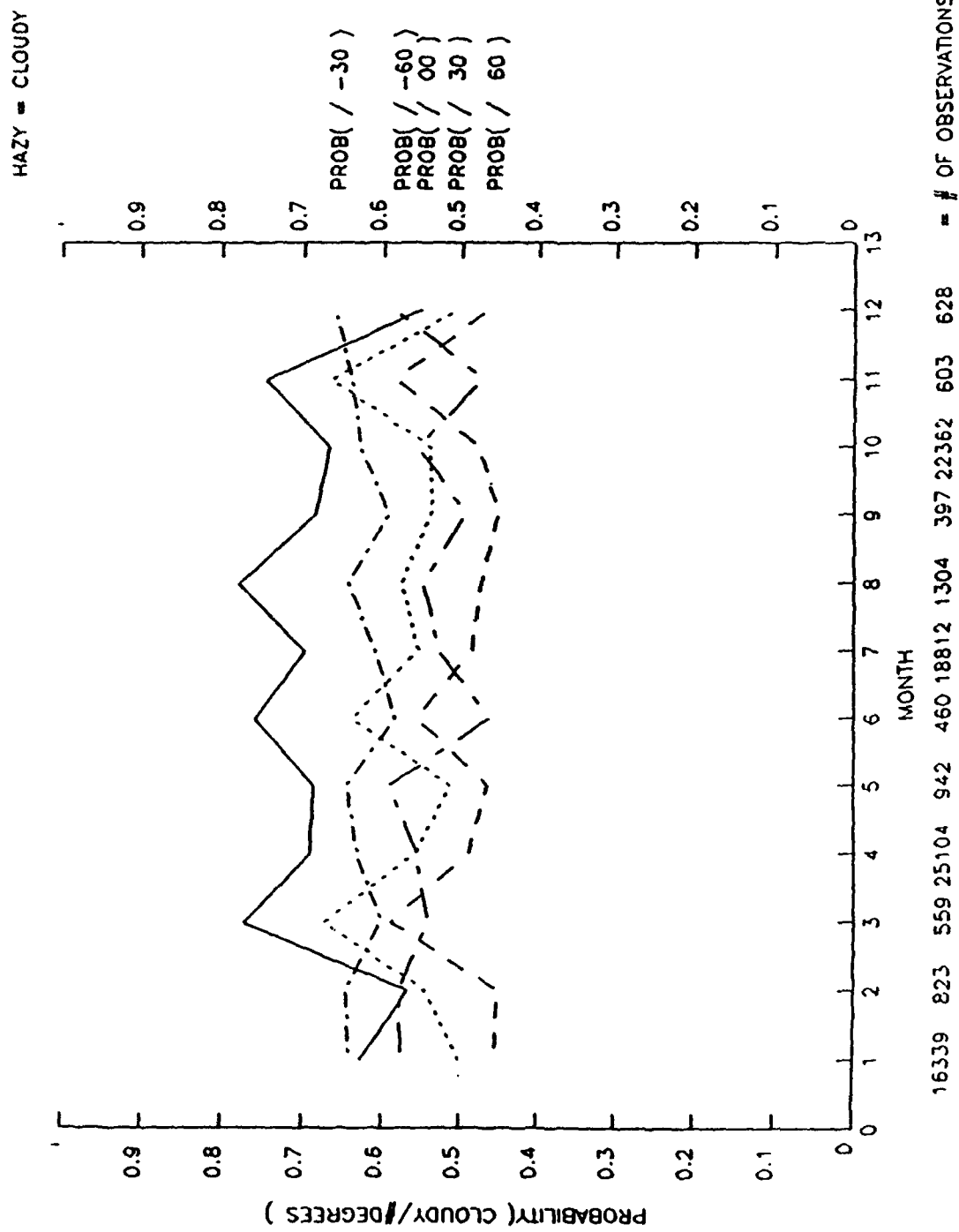


Figure 46. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Cloudy. (Altitudes  $\leq 10,000$  ft)

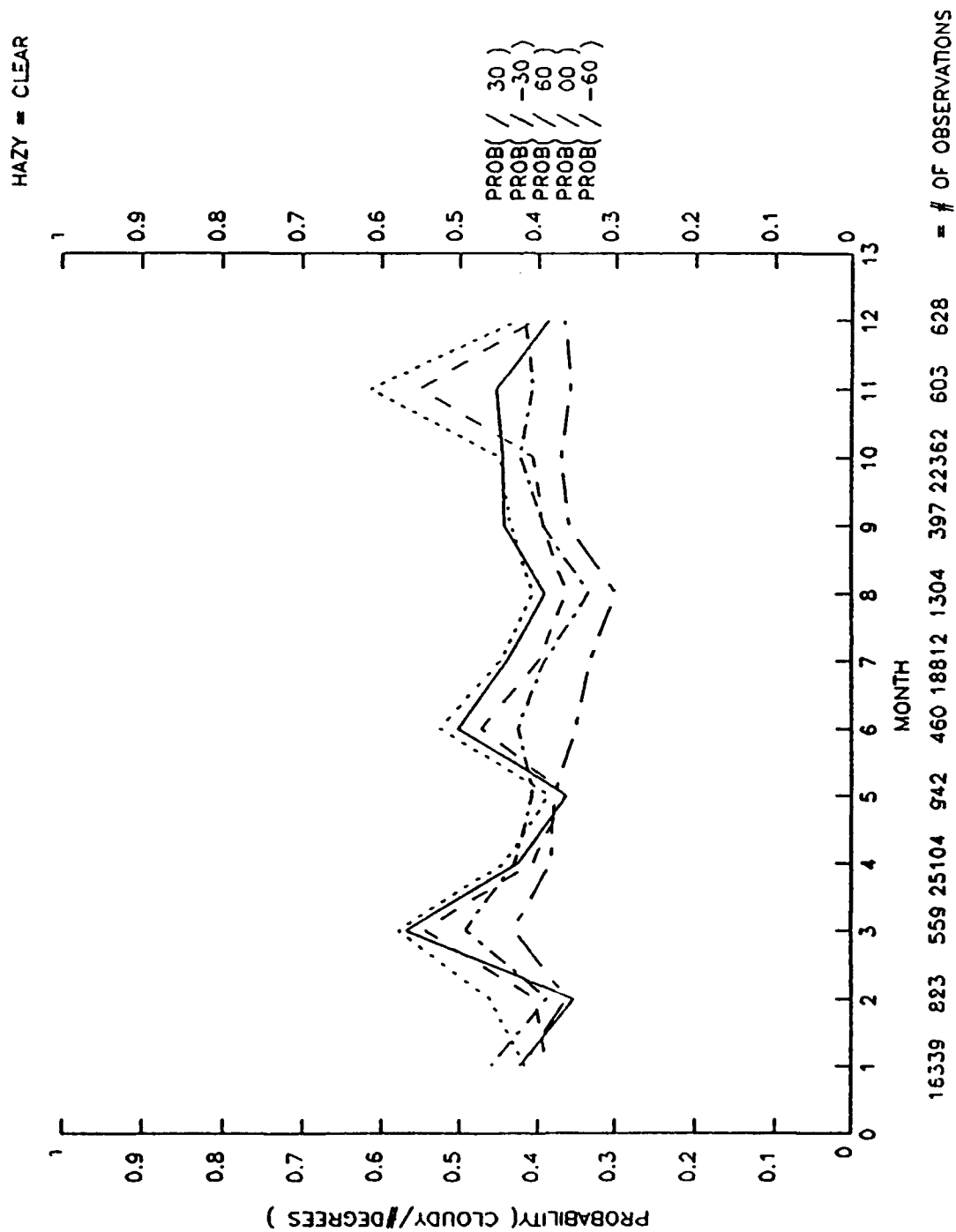


Figure 47. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Clear. (Altitudes  $\leq 10,000$  ft)



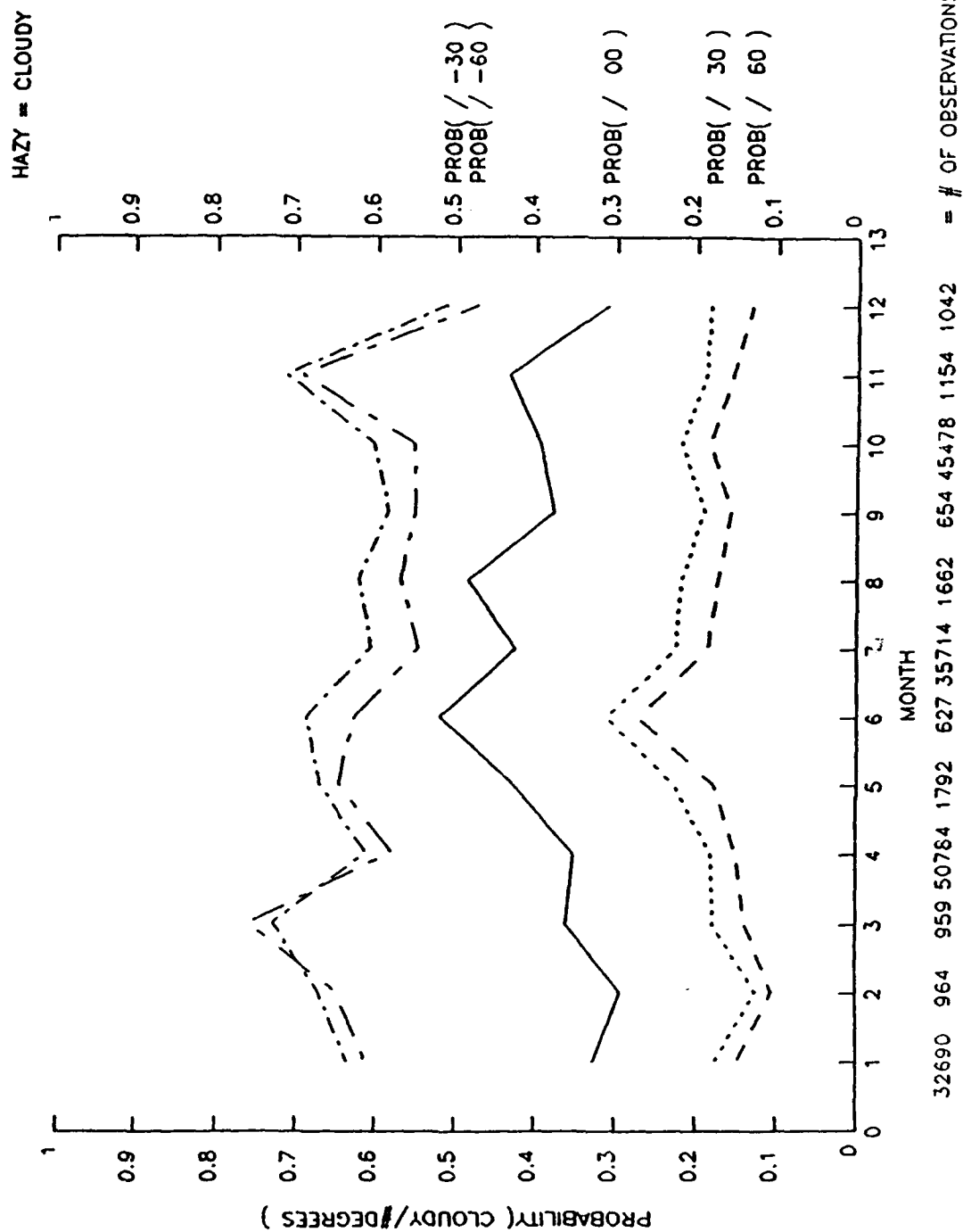


Figure 48. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Cloudy. (Altitudes > 15,000 ft)

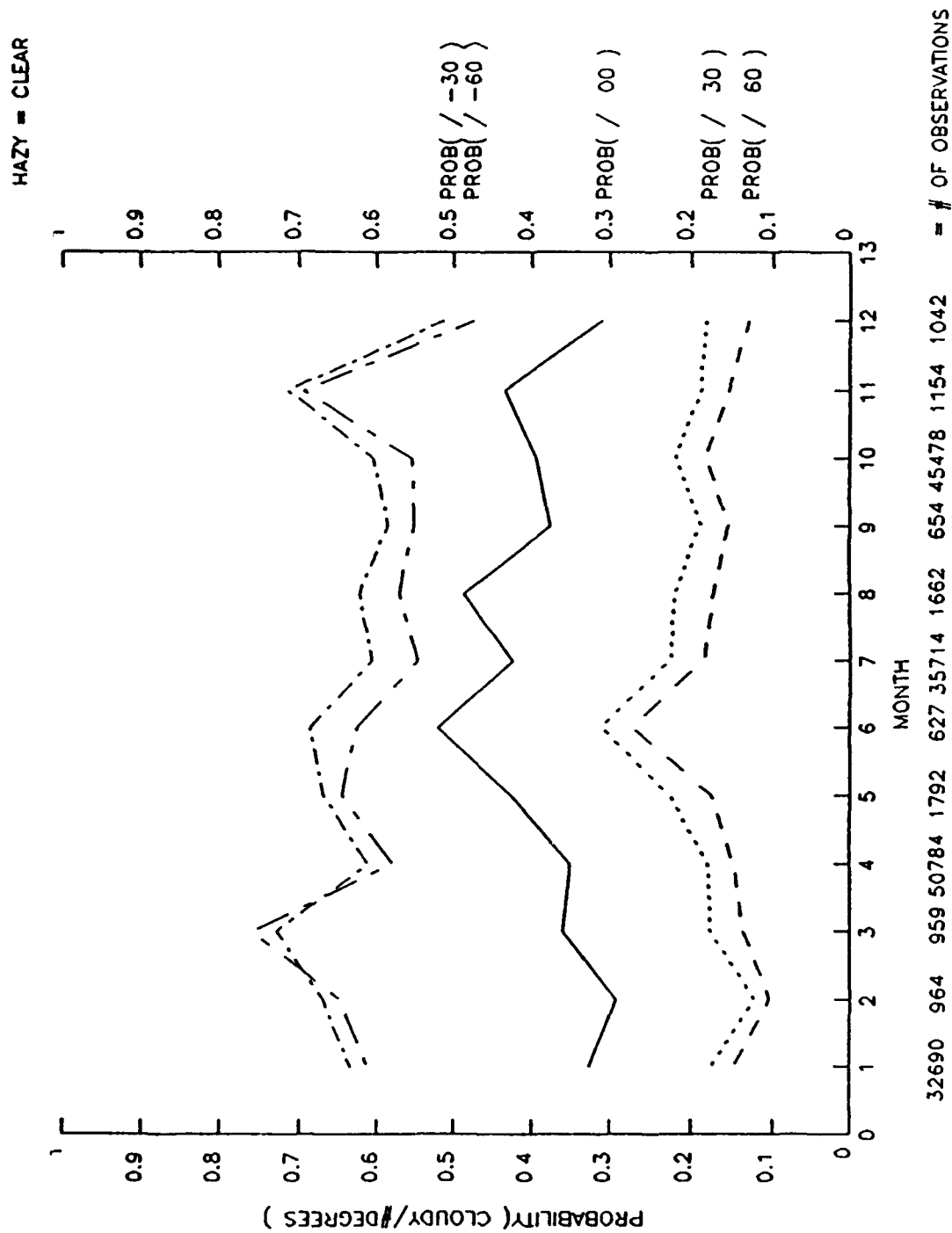


Figure 49. Probability of Cloudy LOS at Indicated Angles for Months. Hazy Is Considered Clear. (Altitudes > 15,000 ft)

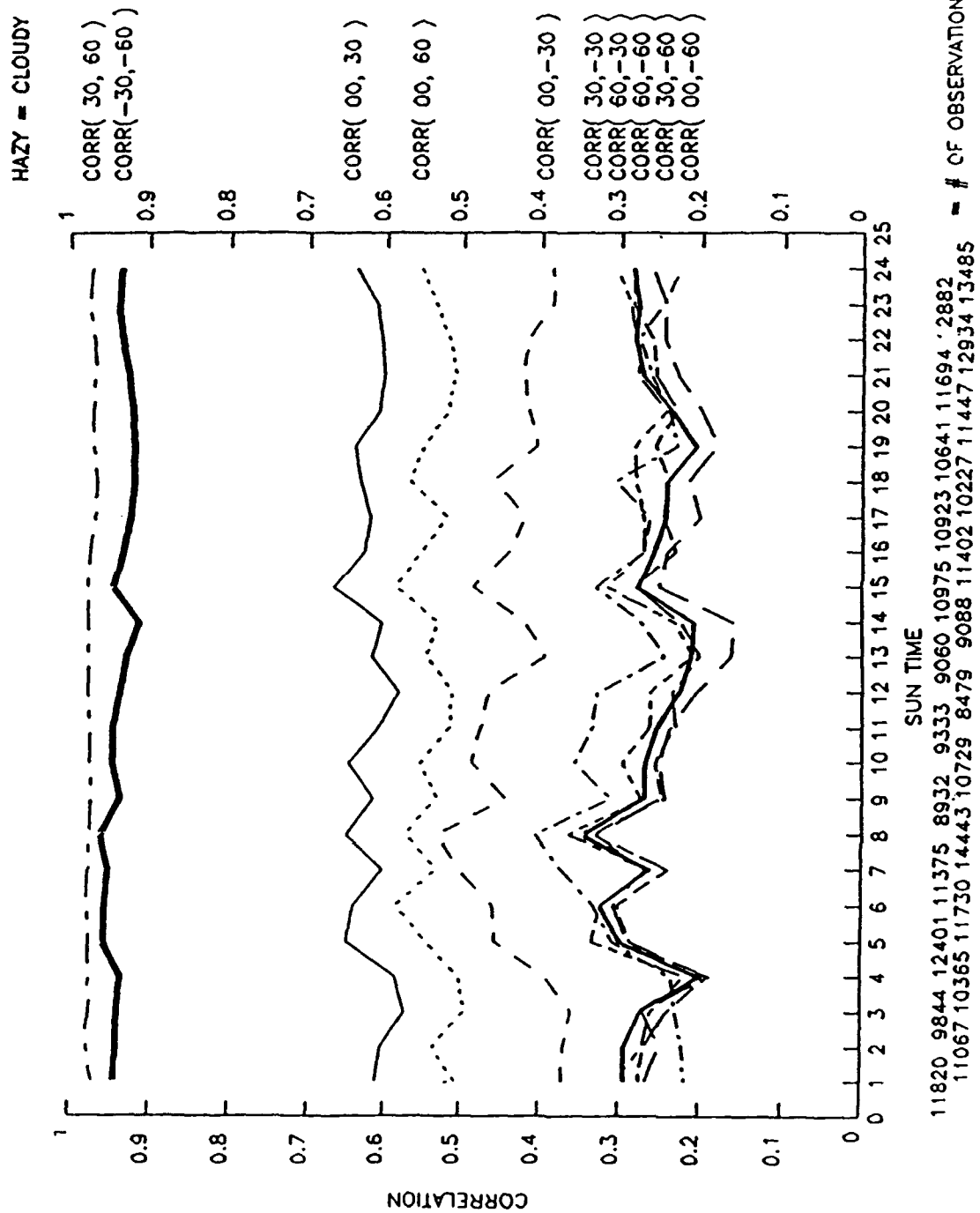


Figure 50. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

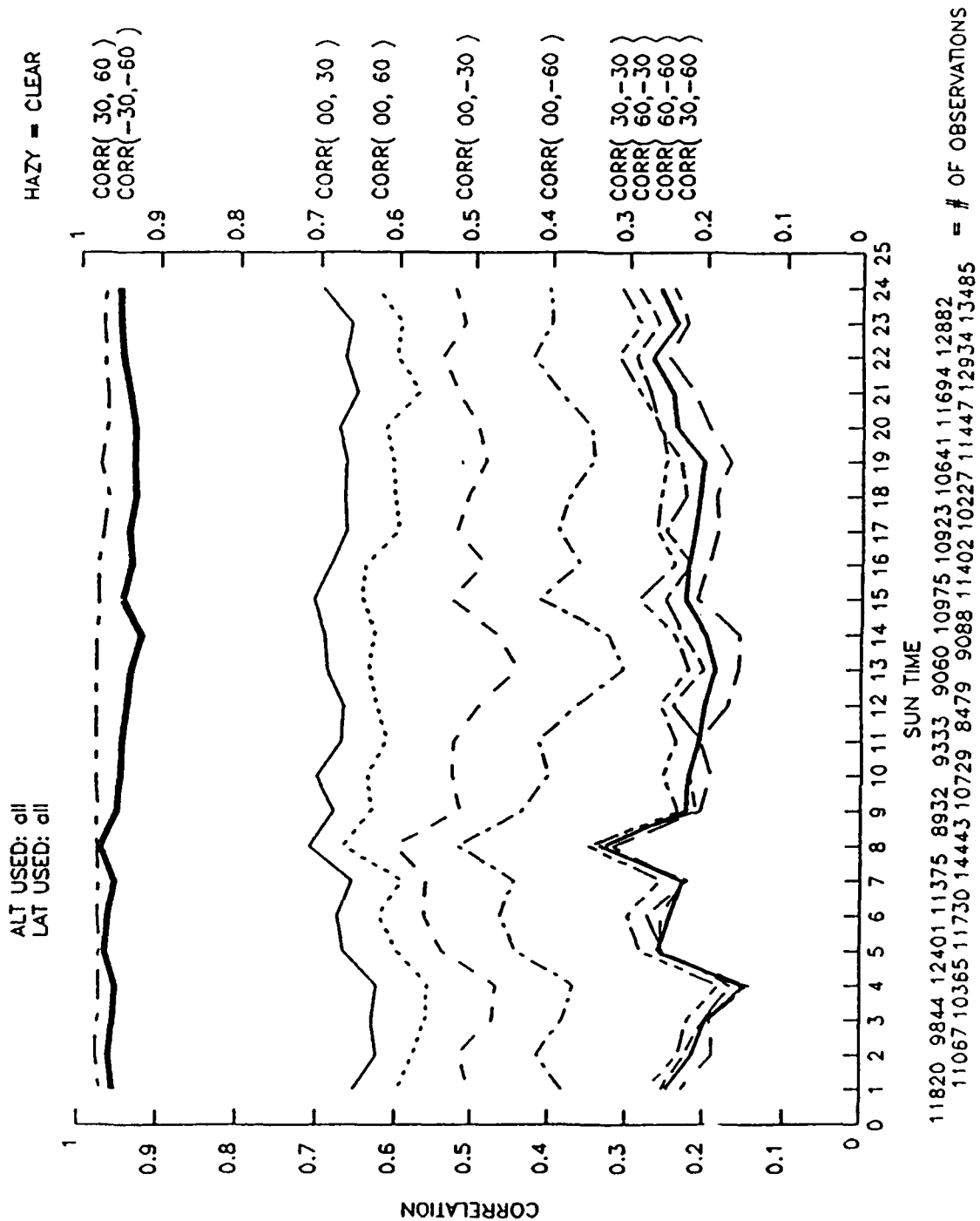


Figure 51. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Clear.

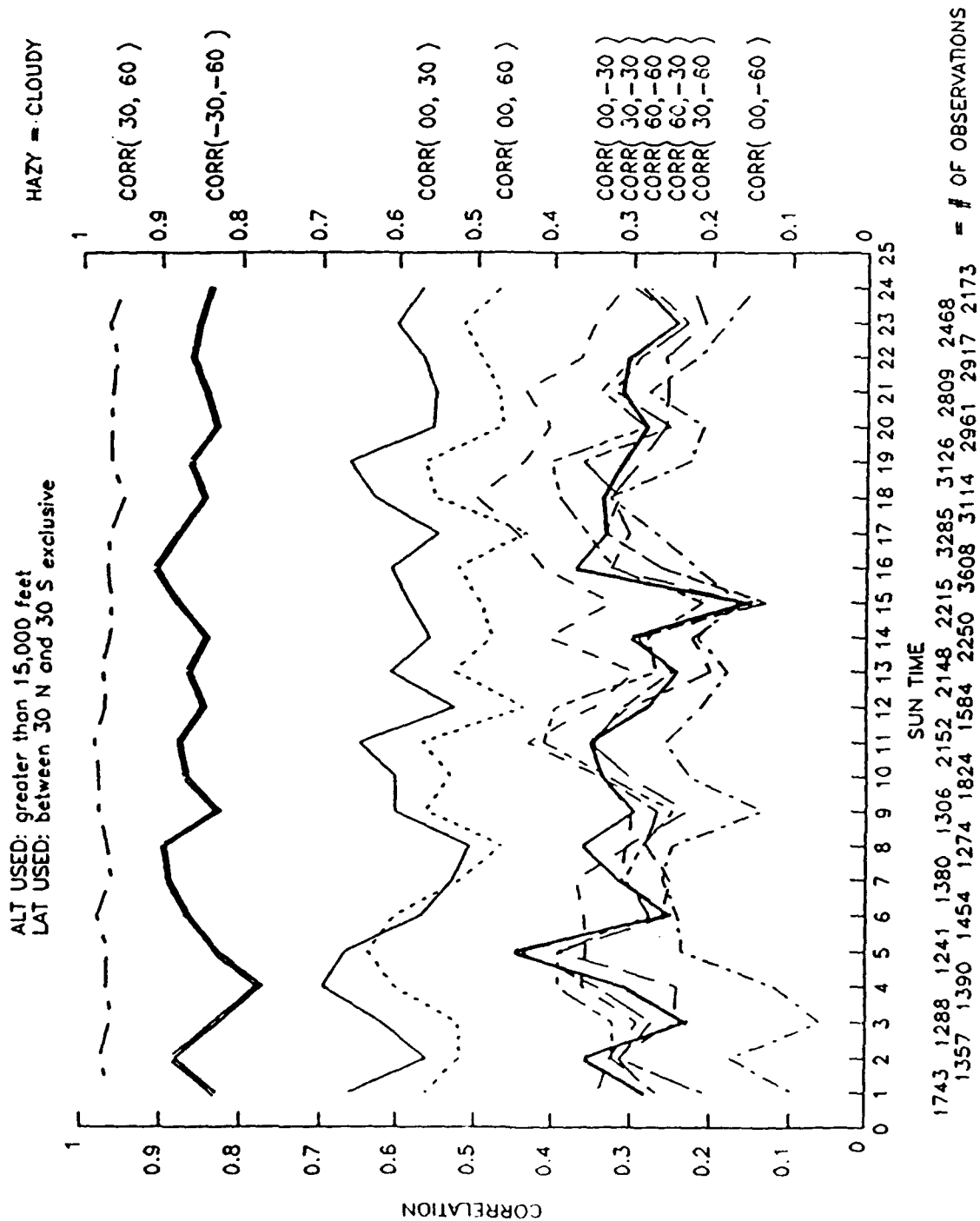


Figure 52. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

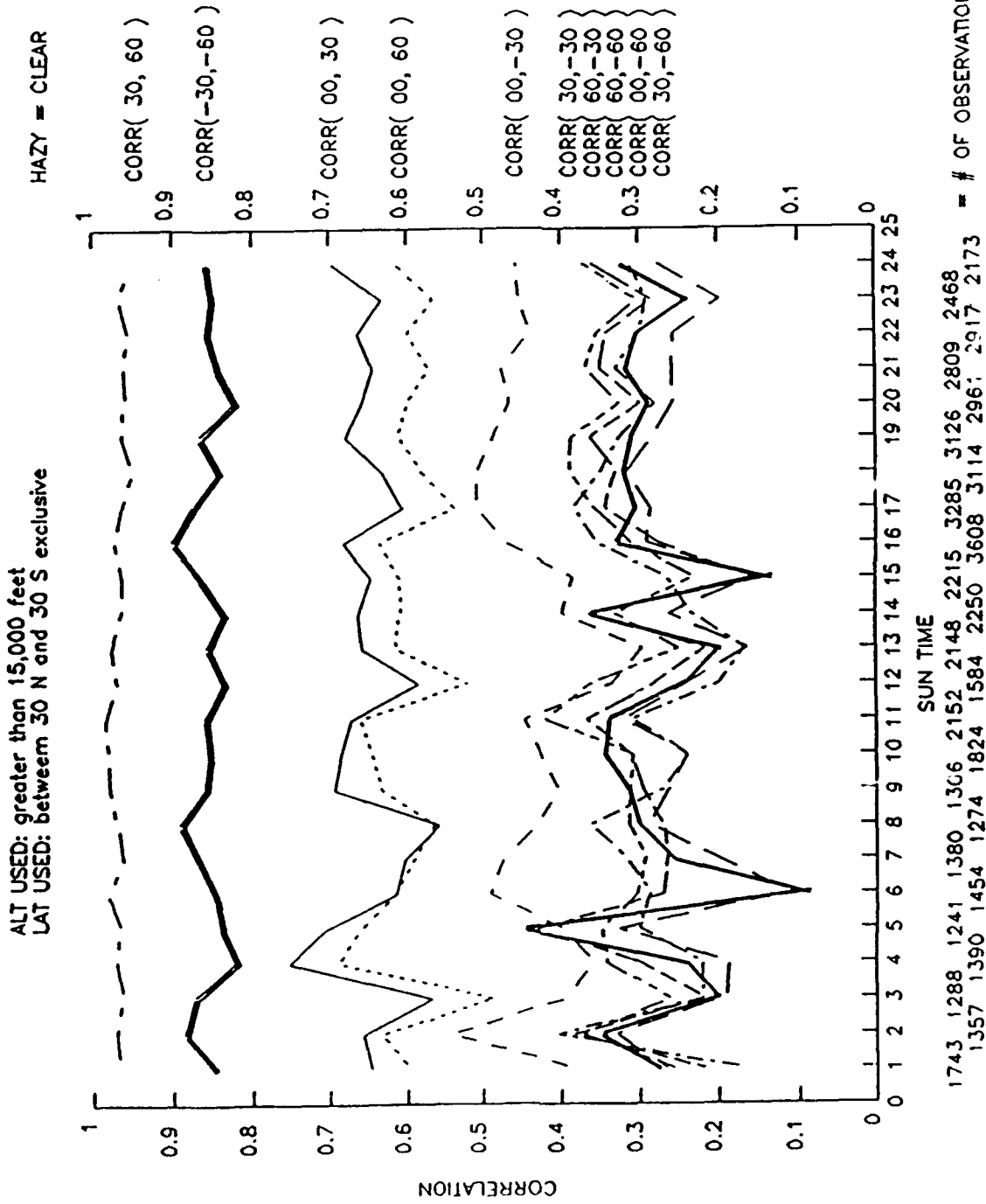


Figure 53. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Clear.

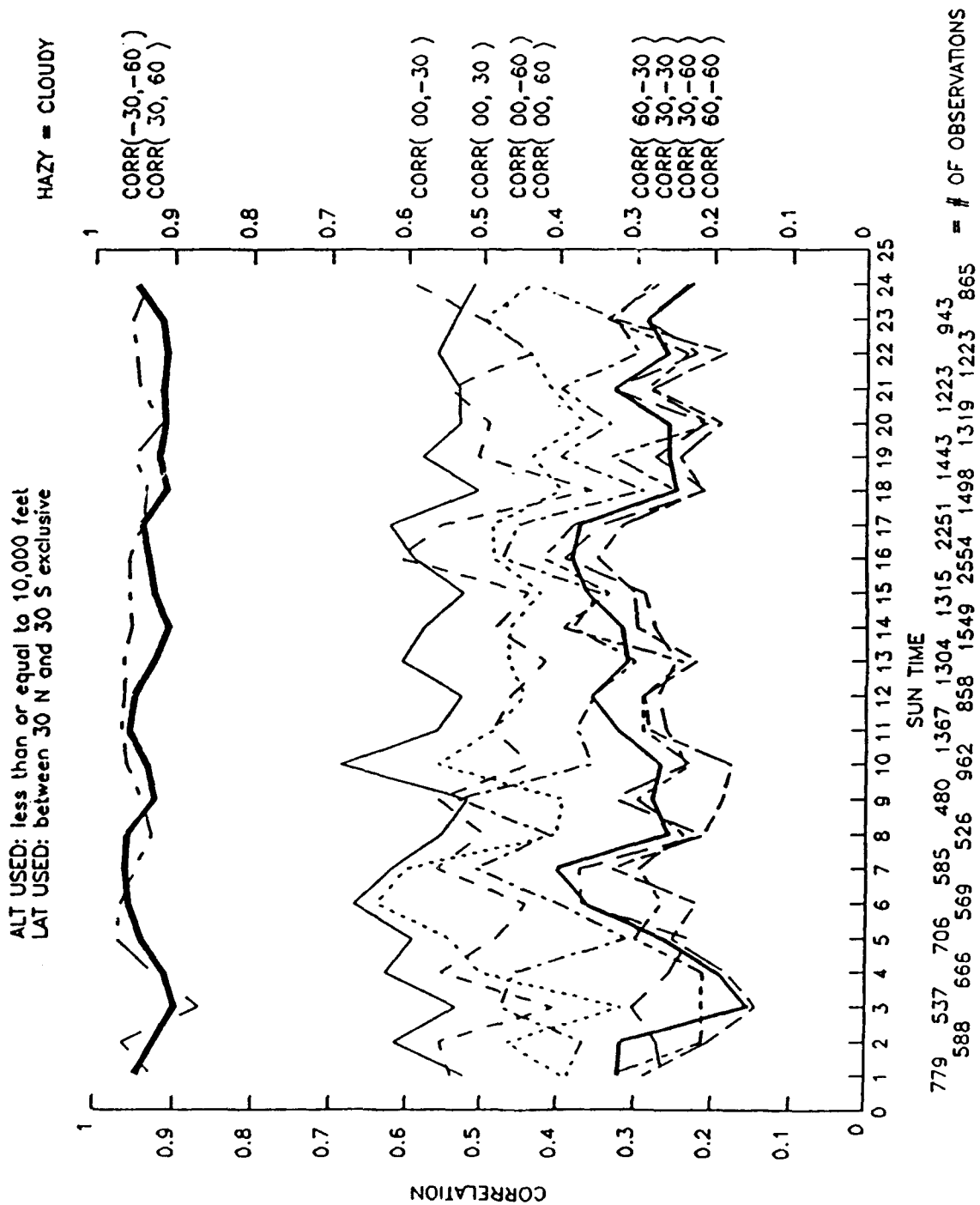


Figure 54. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

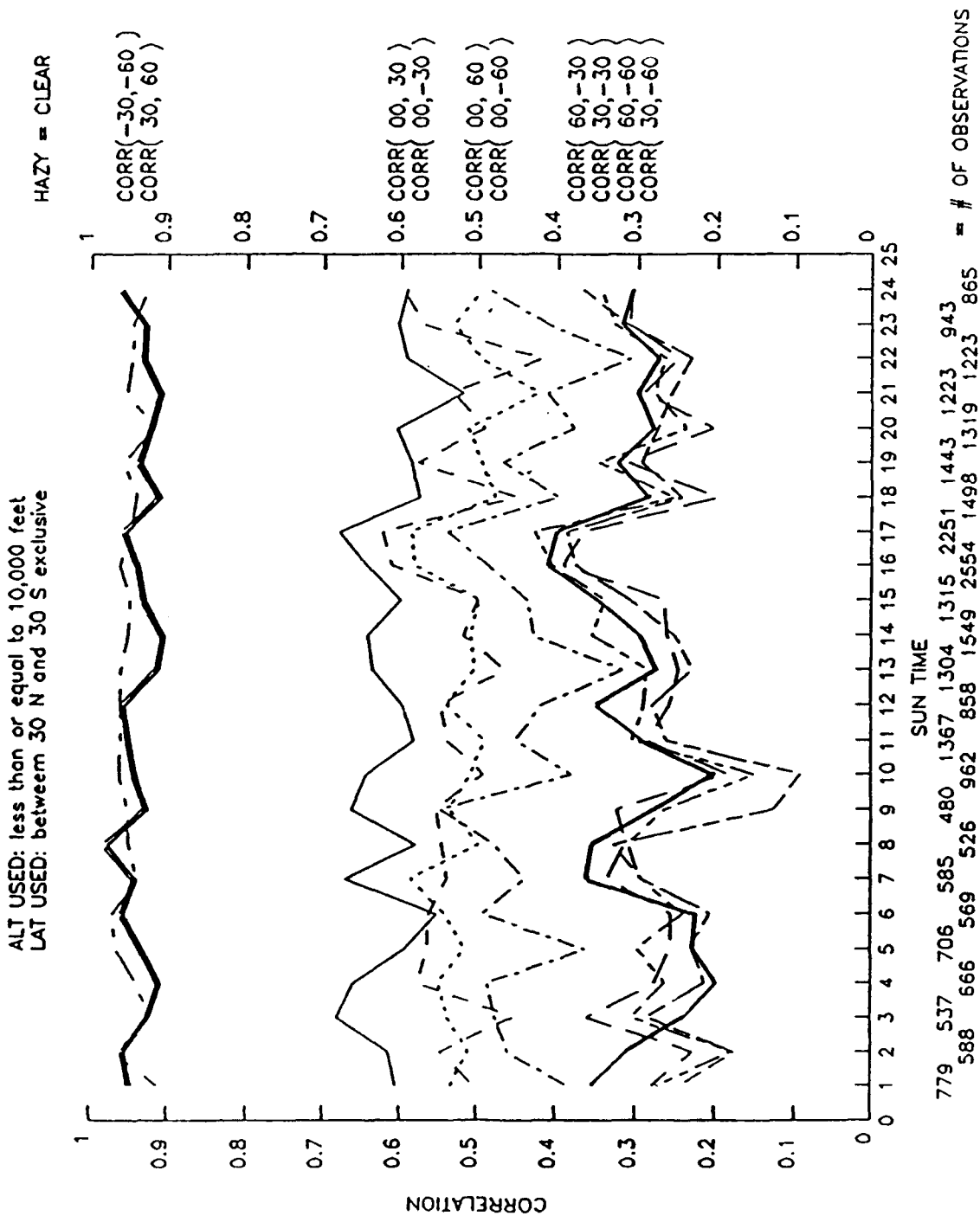


Figure 55. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Clear.



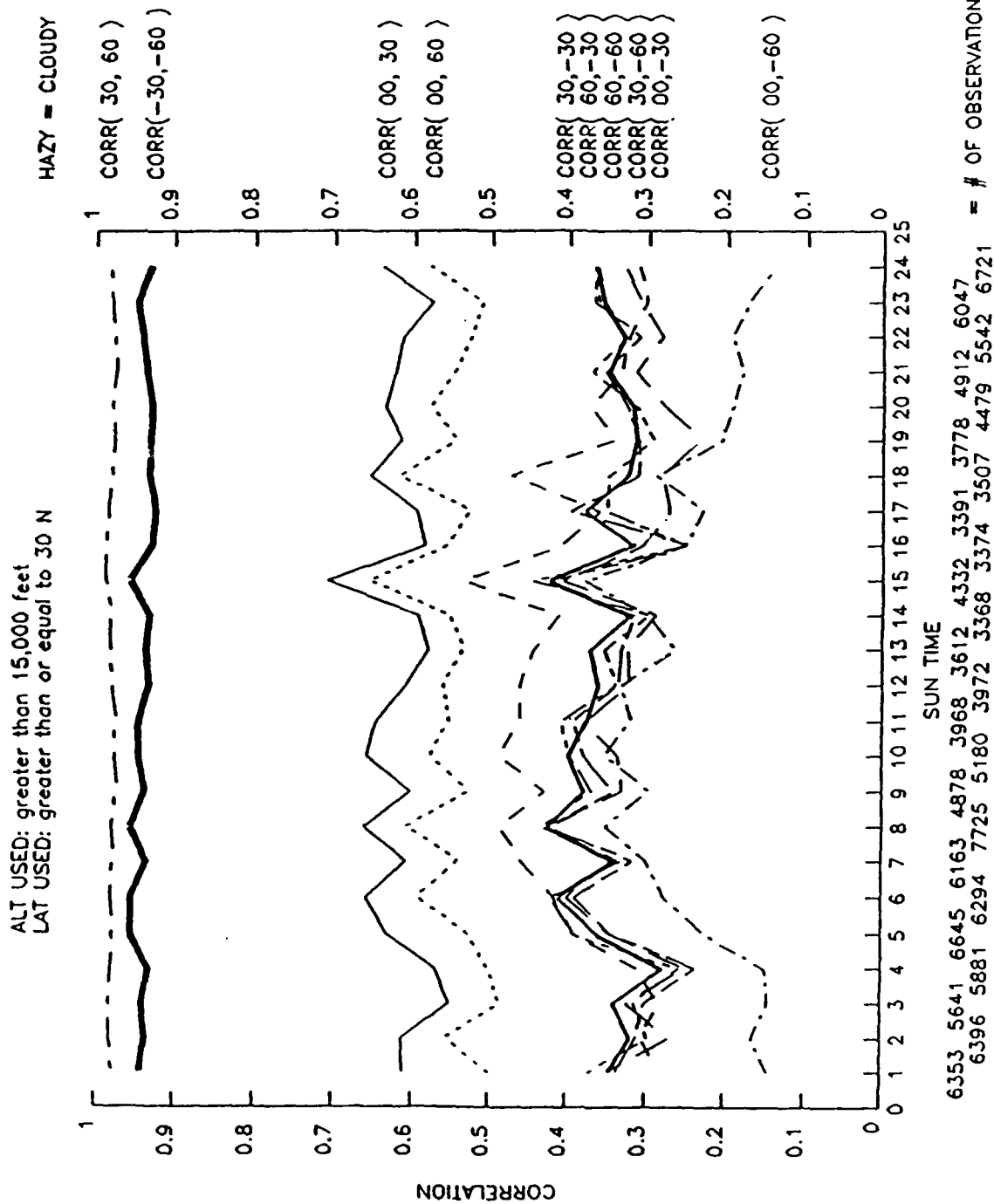


Figure 56. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

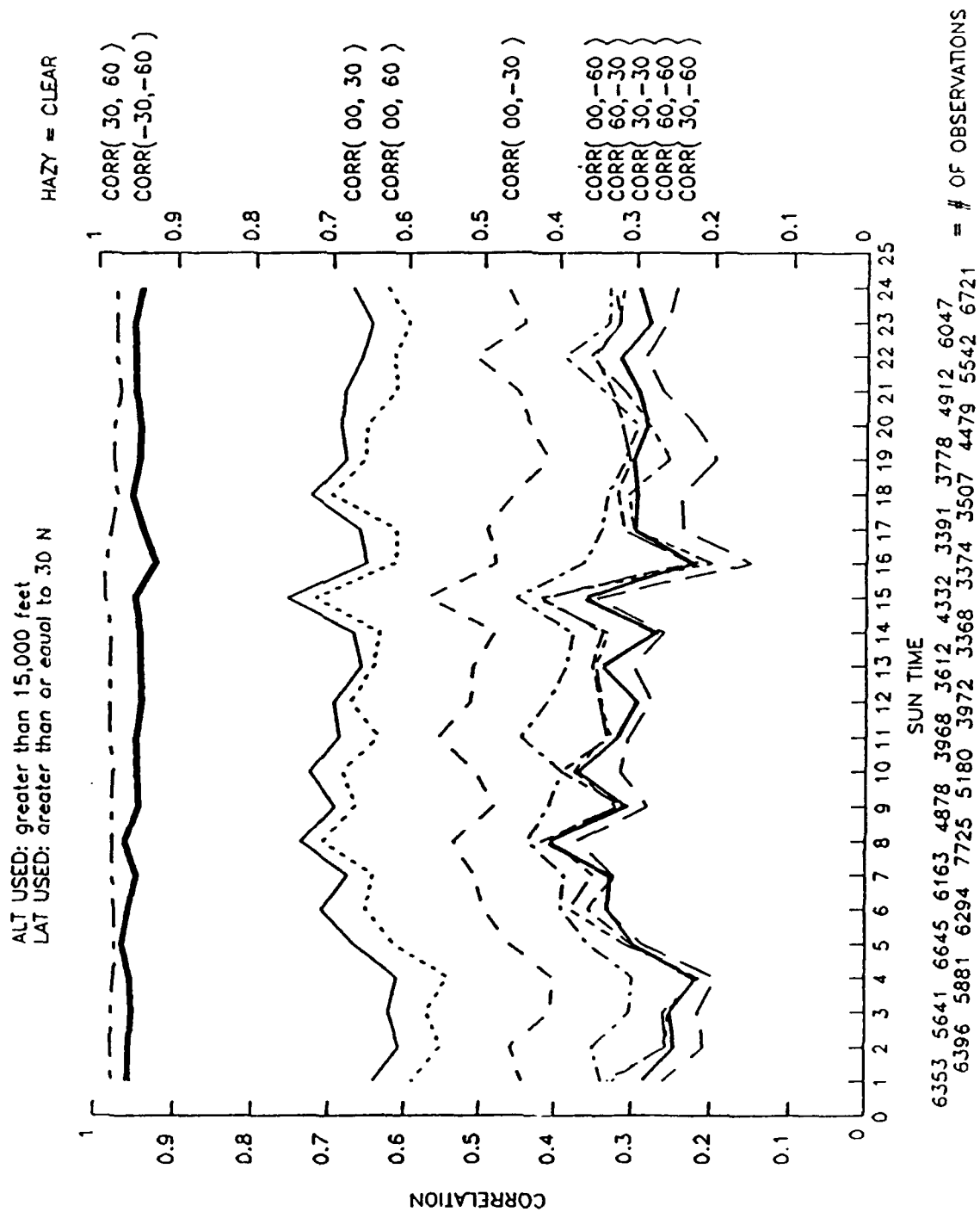


Figure 57. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Clear.

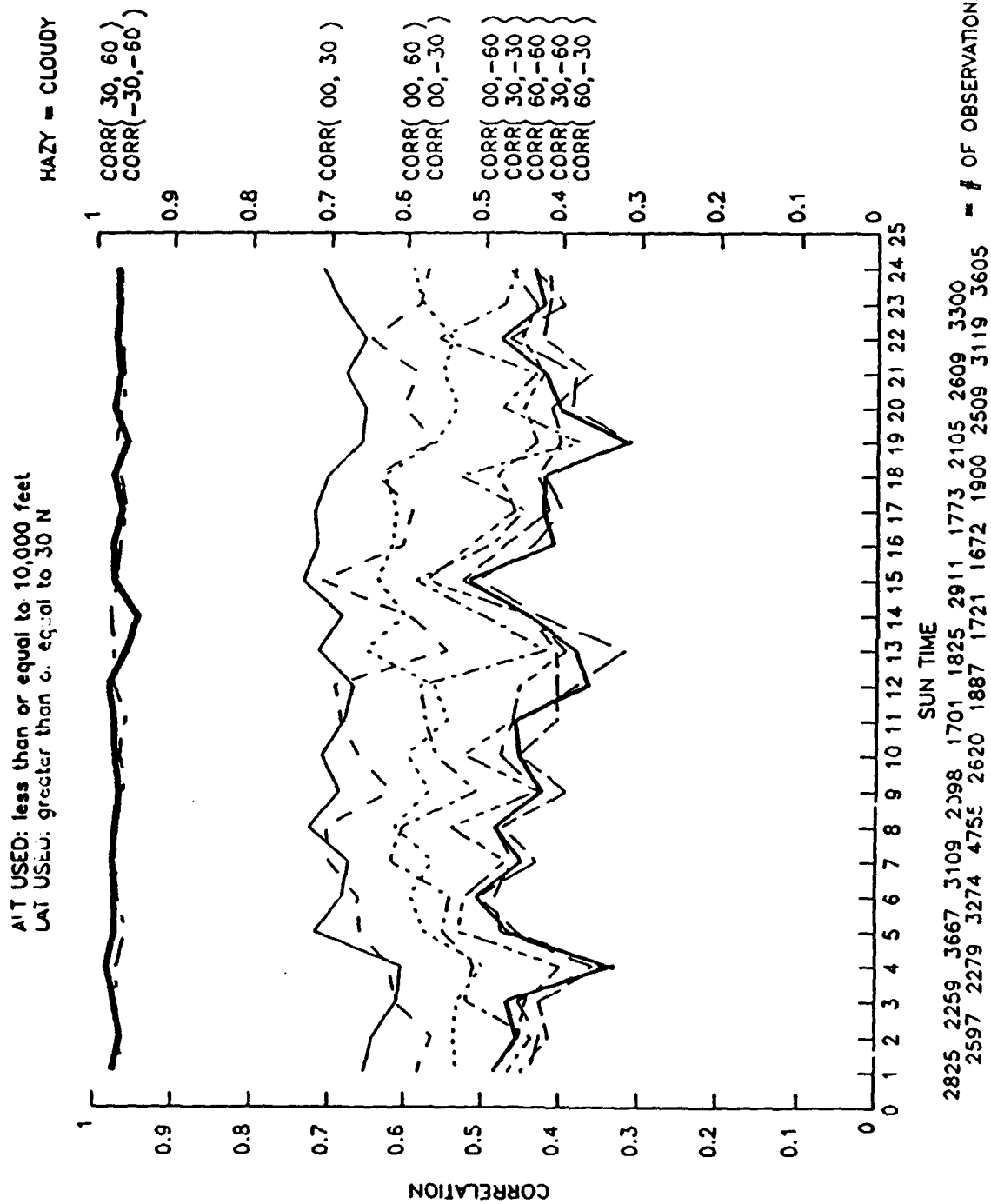


Figure 58. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

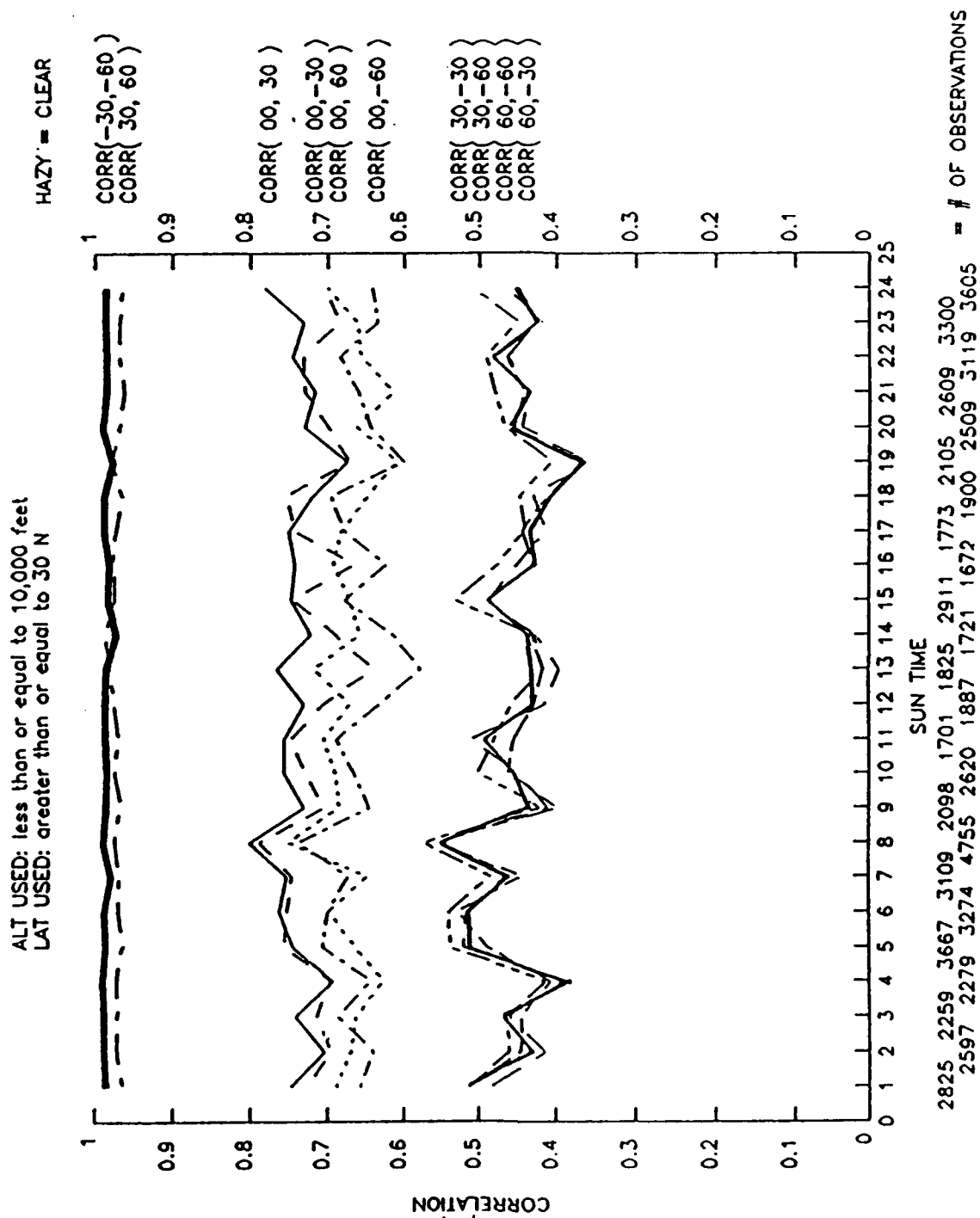


Figure 59. Correlation Between LOS Conditions at Indicated Angles for Sun Times. Hazy Is Considered Clear.

HAZY = CLOUDY

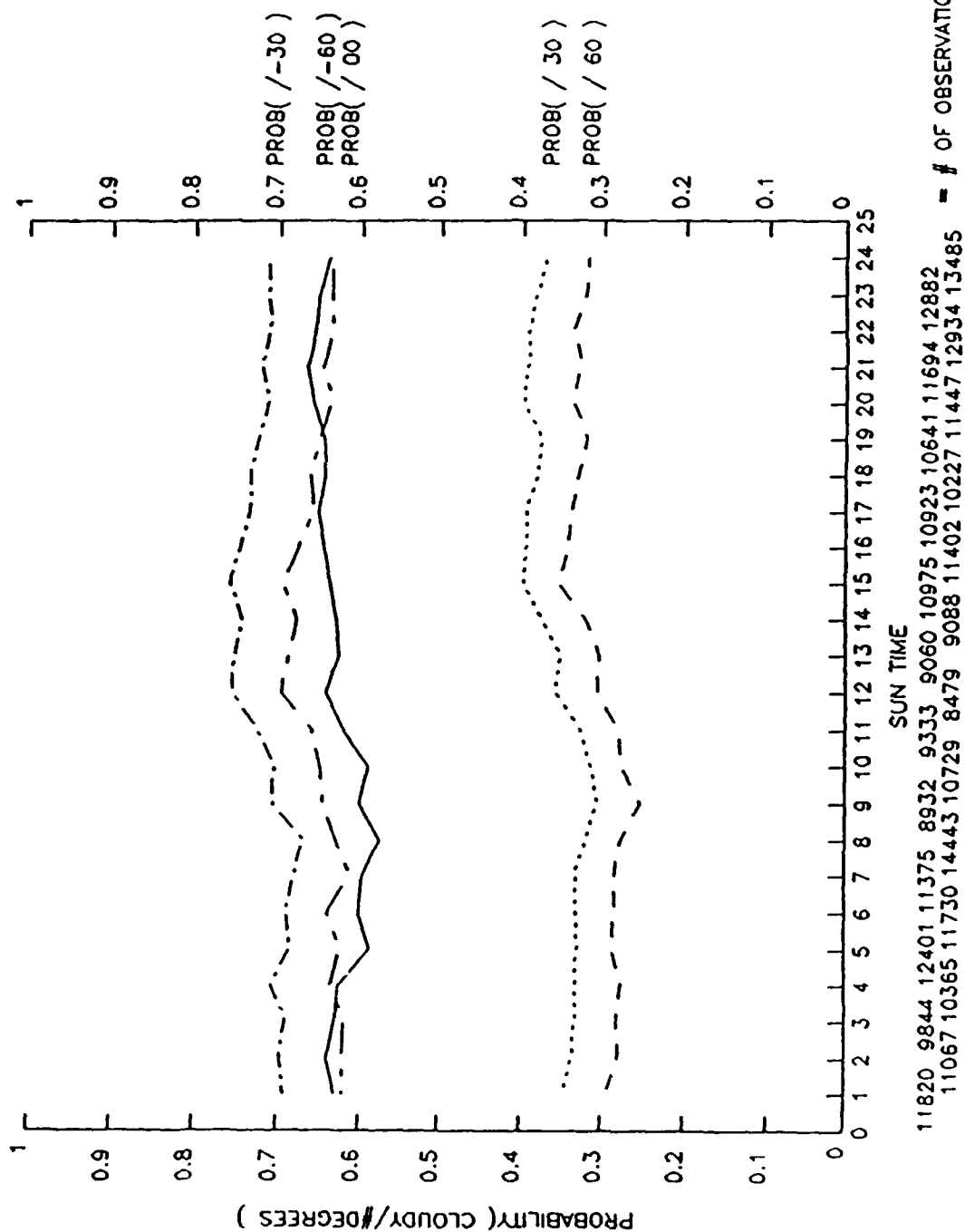


Figure 60. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

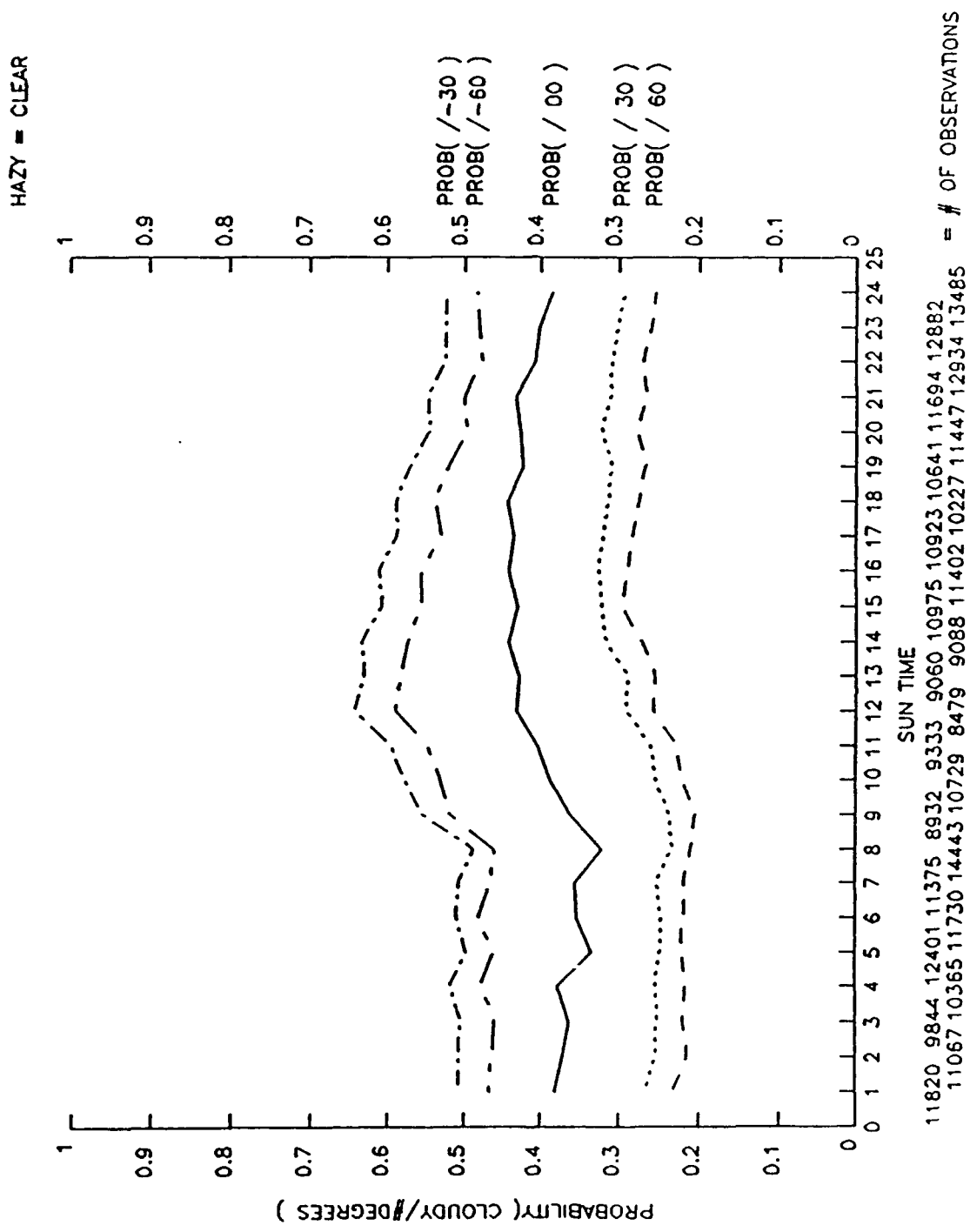


Figure 61. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Clear.

HAZY = CLOUDY

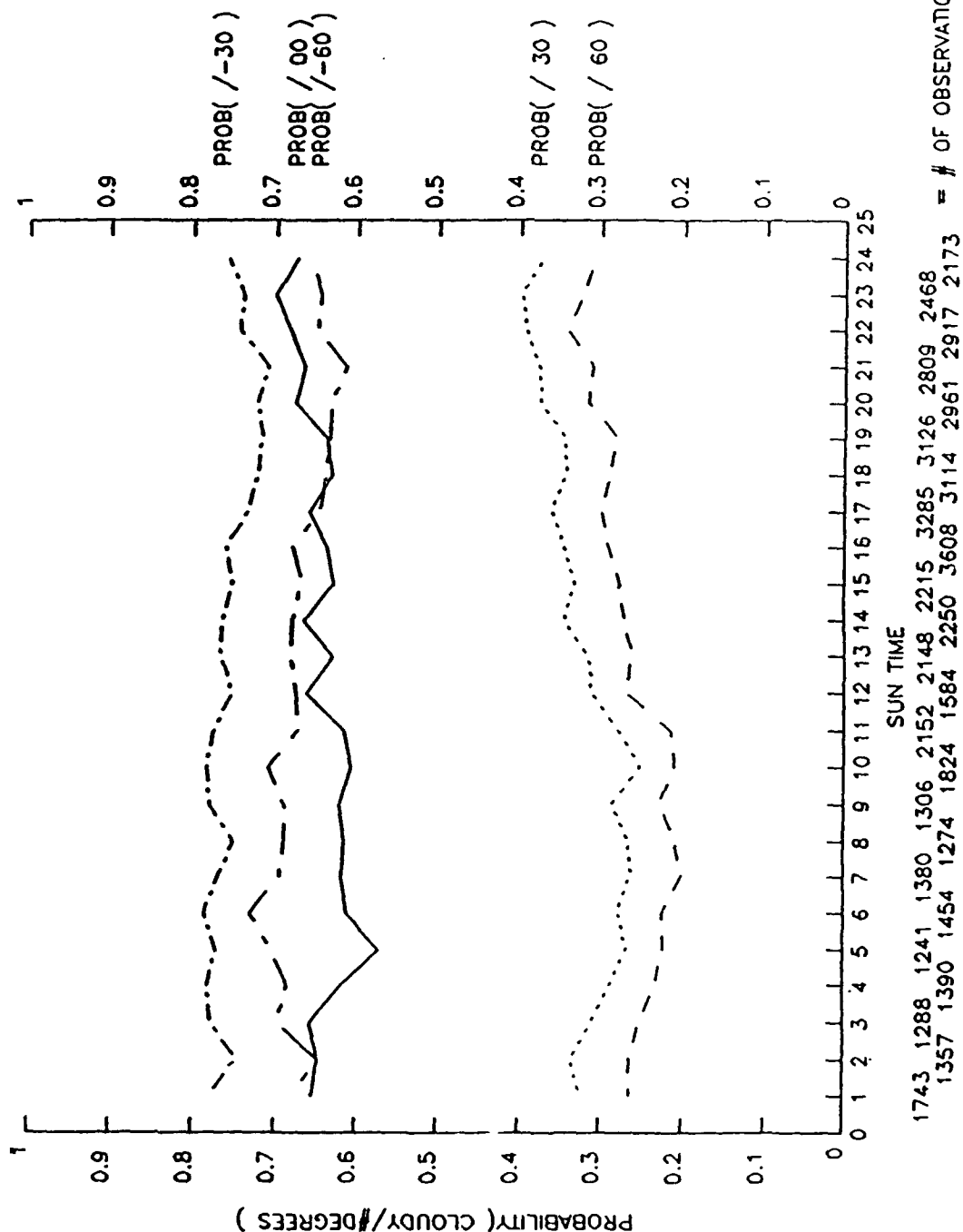


Figure 62. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

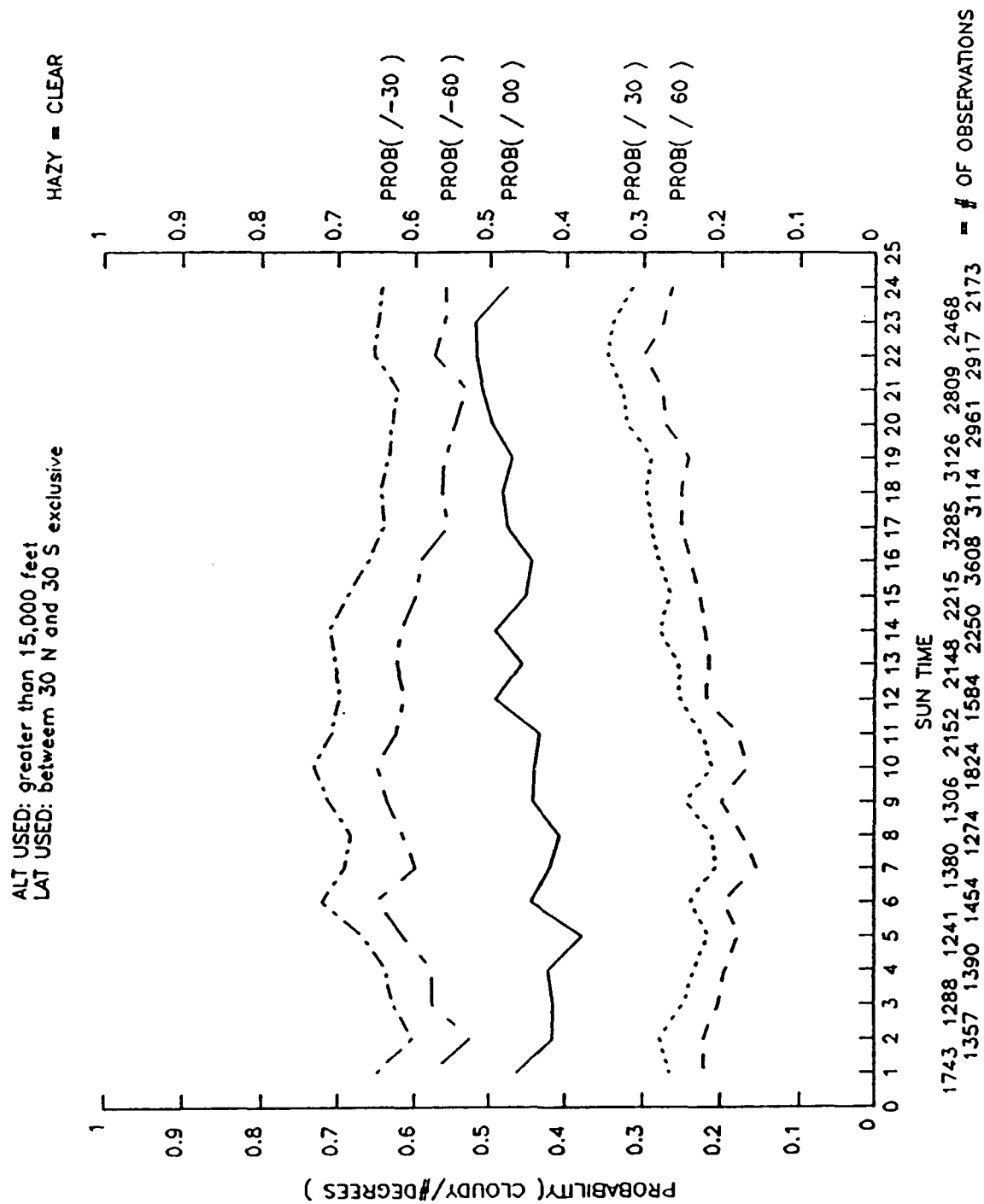


Figure 63. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Clear.



ALT USED: less than or equal to 10,000 feet  
 LAT USED: between 30 N and 30 S exclusive

HAZY = CLOUDY

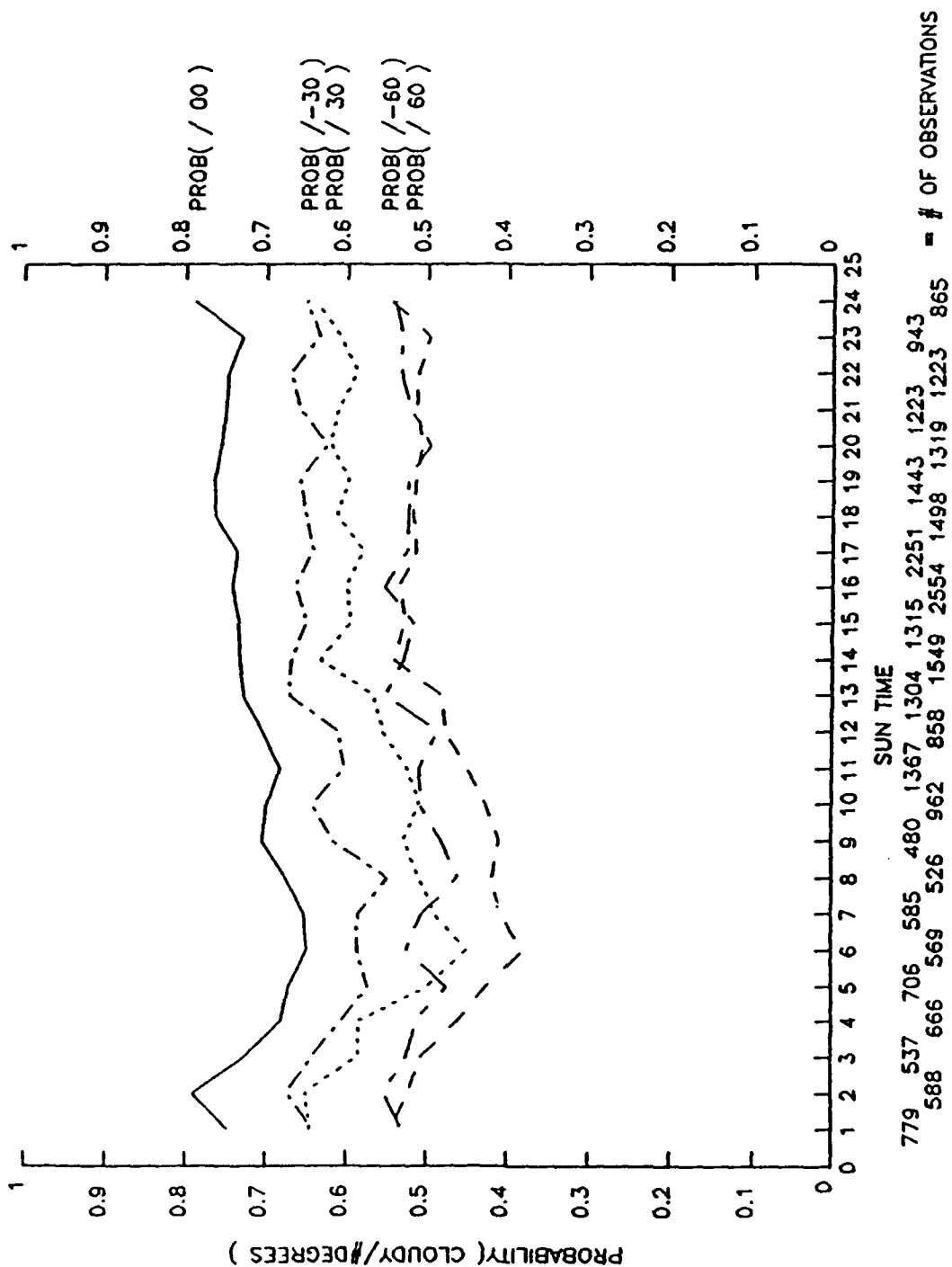


Figure 64. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

ALT USED: less than or equal to 10,000 feet  
LAT USED: between 30 N and 30 S exclusive

HAZY = CLEAR

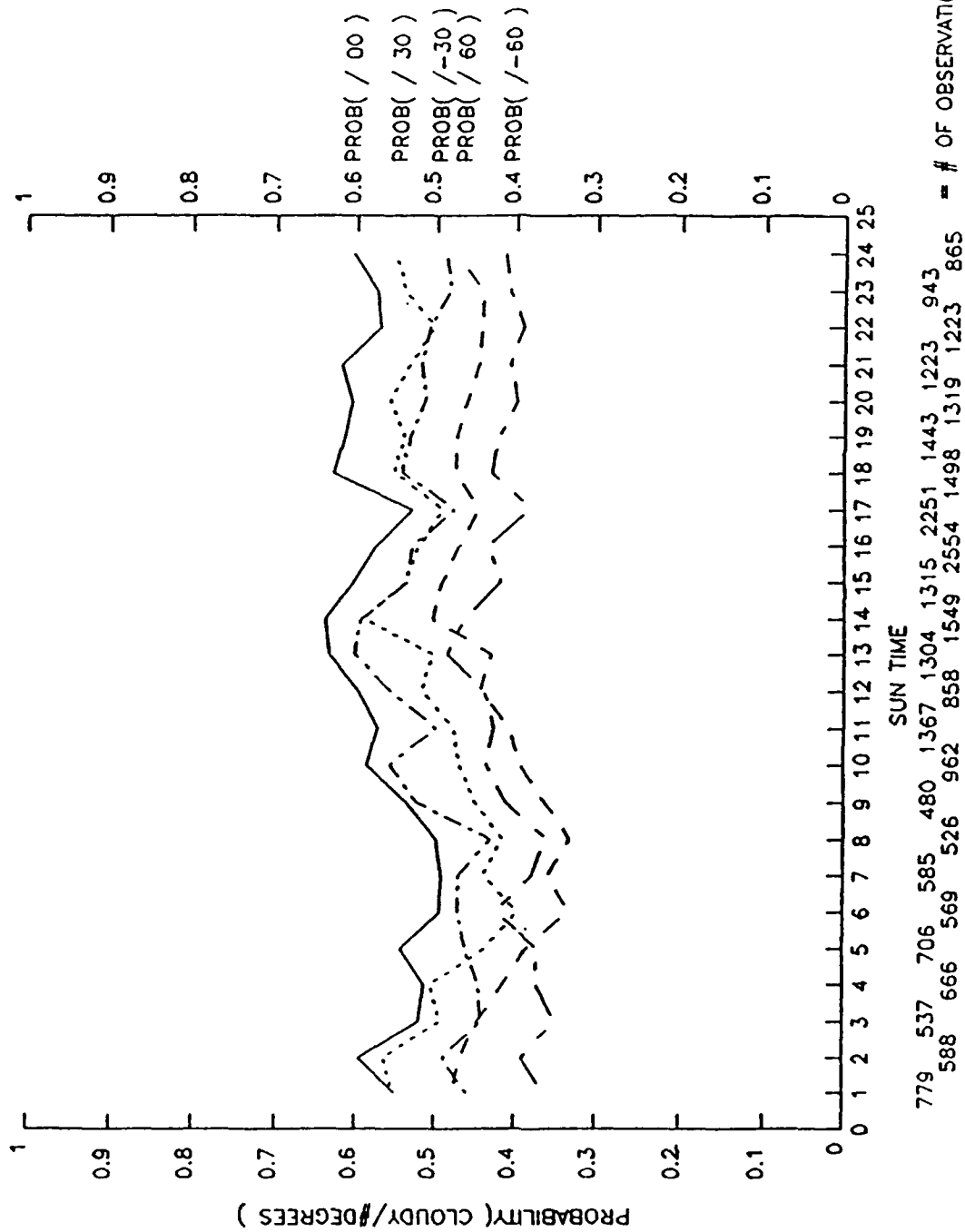


Figure 65. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Clear.

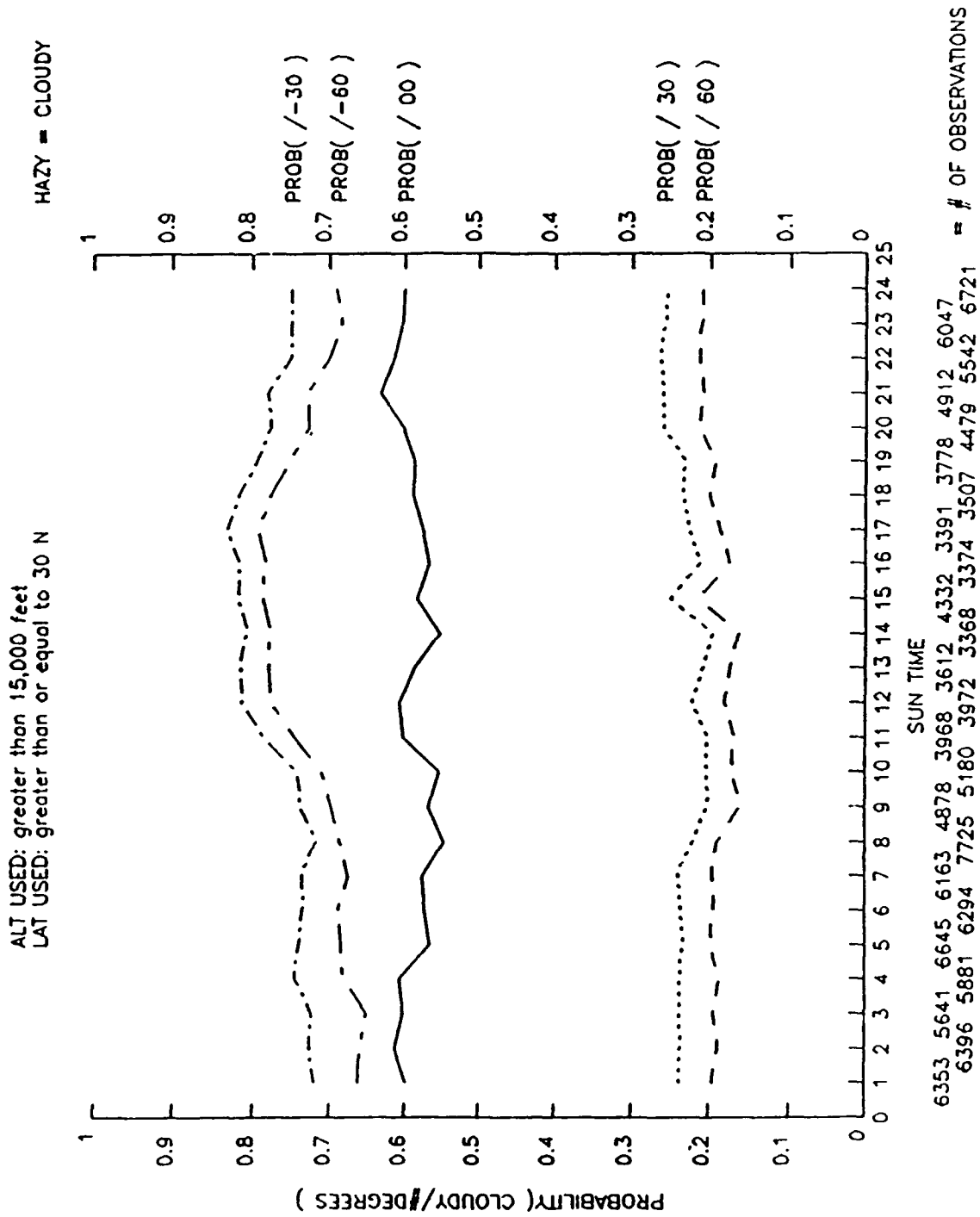


Figure 66. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

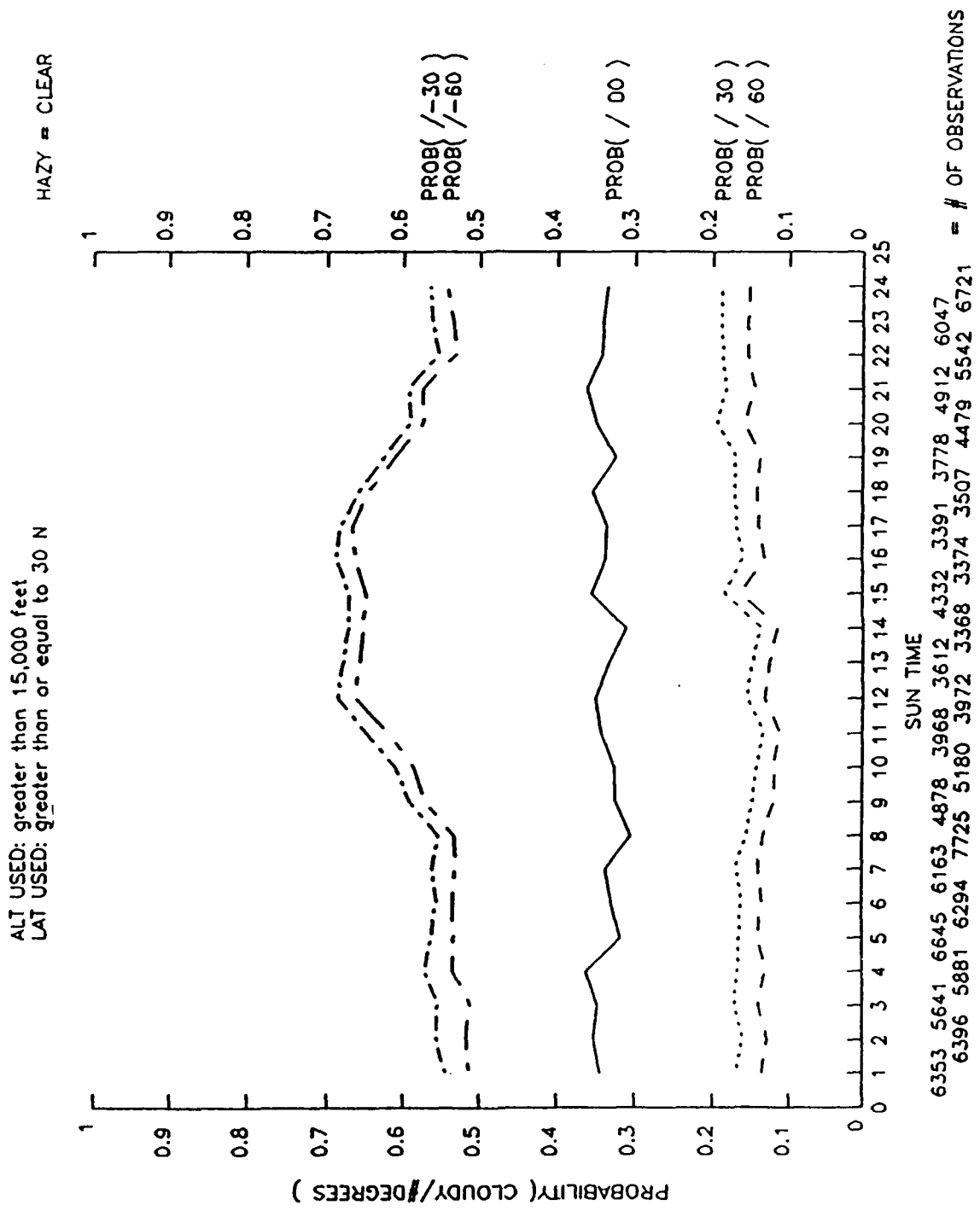


Figure 67. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Clear.

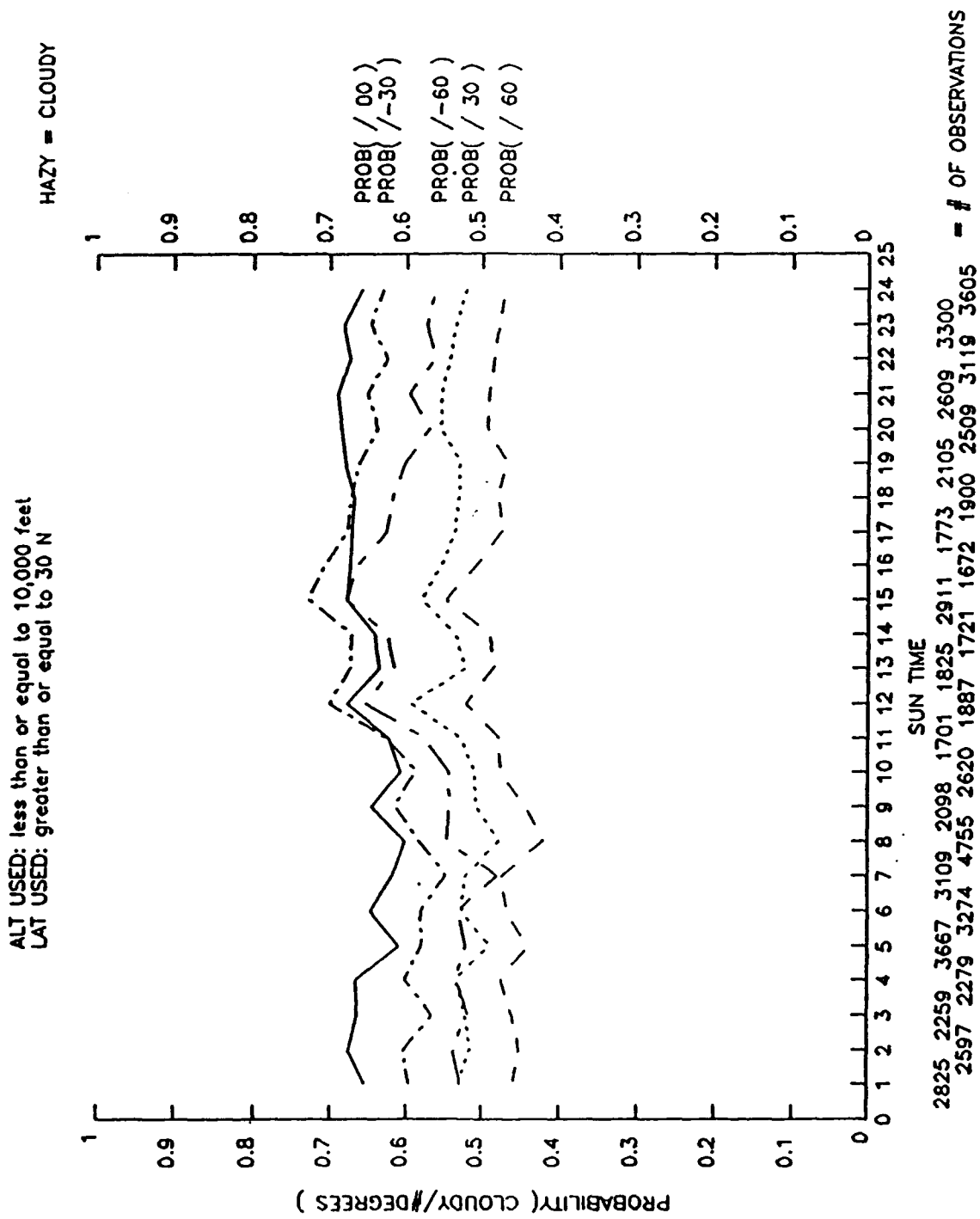


Figure 68. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Cloudy.

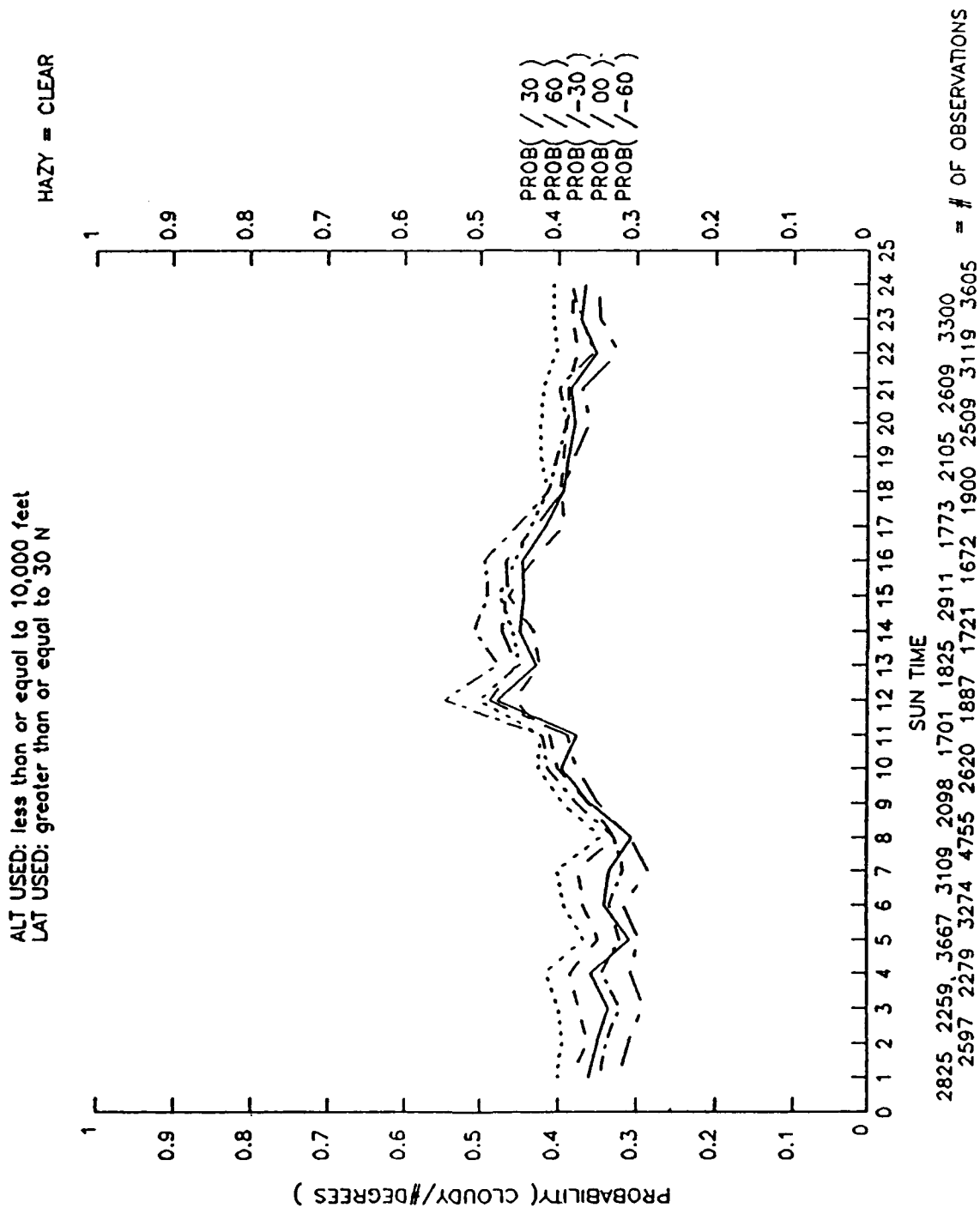


Figure 69. Probability of Cloudy LOS at Indicated Angles for Sun Times. Hazy Is Considered Clear.

## APPENDIX A

```

      FUNCTION TETRA(A,B,C,D)
C      *****
C      ORIGINAL TETRA FUNCTION WAS WRITTEN IN BASIC
C      BY A. BOEHM OF ST SYSTEMS. THIS FORTRAN VERSION
C      WAS ADAPTED FOR THE CDC CYBER 60 BIT COMPUTER
C      BY J. H. WILLAND, ST SYSTEMS, ON 01/03/89.
C
C      PARAMETERS A, B, C, D MAY BE EITHER NORMALIZED ELEMENTS
C      OR ACTUAL COUNTS.
C      REF. BOEHM 1976: TRANSNORMALIZED REGRESSION PROBABILITY,
C      AWSTR-75-259, P24.
C      *****
C      DATA P1/3.1415926536/
C      -----
      R=-999.0
      AD=SQRT(A*D)
      BC=SQRT(B*C)
      IF (AD.LE.0.0.OR.BC.LE.0.0)GO TO 99
C      ----- FIRST GUESS -----
      RSIN=SIN(PI/2.*((AD-BC)/(AD+BC)))
      R=RSIN
      XN=A+B+C+D
      P1=(A+C)/XN
      HQ=-ENORM(P1)
      P2=(A+B)/XN
      QK=-ENORM(P2)
      AN=A/XN
      R1=0.
      D1=P1*P2-AN
C      ----- ITERATIVE SOLUTION -----
      DO 10 K=1,25
        D0=FLNORM(HQ,QK,R)-AN
        IF (ABS(D0).LT.1.0E-7)GO TO 99
        RS=R
        IF (ABS(D0-D1).LT.1.0E-7)GOTO 99
        R=R-D0*(R1-R)/(D1-D0)
        D1=D0
        R1=RS
        IF (ABS(R).GE.1.0)R=(SIGN(R,R)+RS)/2.
10    CONTINUE
99    TETRA=R
      RETURN
      END

```

```

FUNCTION TFUNC(HQ,A)
DATA P1/3.1415926536/
C *****
C BINORMAL SECTOR INTEGRAL.
C REF. YAMAUTI, (1972): STAT. TABLES AND FORMULAS WITH COMPUTER
C APPLICATIONS, JAP. STAT. ASSOC., PROGRAM 15.
C *****
IF (ABS(HQ).LE.1.0E-50) GO TO 20
A1=ABS(A)
H1=HQ
IF (A1.LT.1.0) GO TO 9
H1=A1*HQ
A1=1./A1
9 AA=A1*A1
HH=H1*H1/2.
D1H=ALOG(HH)
SUM2=EXP(-HH)
SUM1=1.-SUM2
FACT=0.0
S=-AA
DO 10 J=1,80
X=J
FACT=FACT-ALOG(X)+D1H
SUM2=SUM2+EXP(-HH+FACT)
C=S*(1.-SUM2)/(2.*X+1.)
SUM1=SUM1+C
IF (ABS(C).LT.1.0E-10) GO TO 11
S=-S*AA
10 CONTINUE
PRINT 100,HQ,A
100 FORMAT(" TFUNC HQ A",2F10.4,1X,"DID NOT CONVERGE.")
11 T=(ATAN(A1)-SUM1*A1)/(2.*P1)
IF (ABS(A).LE.1.0) GO TO 19
AA=PNORM(-HQ)
HH=PNORM(-H1)
T=(AA+HH)*.5-AA*HH-T
19 IF (A.LT.0.0) T=-T
TFUNC=T
GO TO 99
20 TFUNC=ATAN(A)/(2.*P1)
99 RETURN
END

FUNCTION TFUNC2(A,B,C)
C *****
C AVOIDS DIVISION BY ZERO.
C *** *****
IF (ABS(C).LT.1.0E-8) THEN
Y=SIGN(B,B)*(1.0-PNORM(ABS(A)))/2.
TFUNC2=Y
ELSE
TFUNC2=TFUNC(A,B/C)
ENDIF
RETURN
END

```



```

      FUNCTION PNORM(E)
C      *****
C      END TO PROBABILITY
C      CUMULATIVE NORMAL.
C      INTEGRAL OF THE STANDARD NORMAL DISTRIBUTION
C      FROM INFINITY TO E.
C      REF. ABRAMOWITZ AND STEGUN (1964); HANDBOOK OF
C      MATH. FUNCTIONS, NBS, EQ. 9.7.1, 19.
C      *****
      A=ABS(E)
      A=(((((5.621326E-6*A+5.105517E-5)*A+3.968616E-5)*A+3.422739E-3)
X*A+2.2077E-2)*A+5.207516E-2)*A+1.+4.627378E-2)
      A=A**(-16)
      IF (E.GT.0.0) A=1.-A
      PNORM=A
      RETURN
      END

```

```

      FUNCTION ENORM(P)
C      *****
C      PROBABILITY TO EQUIVALENT NORMAL DEViate (END)
C      ALGORITHM AS111, APPL STAT 26 1977 P118.
C      INVERSE OF STANDARD NORMAL DISTRIBUTION
C      INTEGRATION FOUND IN PNORM.
C      *****
      Q=P-.5
      IF (ABS(Q).GT.0.42) GOTO 10
      R=Q*Q
      R=D*((( -25.44106*R+41.3912)*R-18.615)*R+2.506628) /
X (( (3.130829*R-21.06224)*R+23.08337)*R-8.473511)*R+1.)
      ENORM=R
      RETURN
10  IF (Q.LE.0.0) THEN
      R=P
    ELSE
      R=1.-P
    ENDIF
      IF (R.LT.(1.0E-500) R=1.0E-500)
      R=SQRT(-ALOG(R))
      R=(( (2.321213*R+4.0770141)*R-2.297965)*R-2.787189) /
X ((1.637068*R+3.543889)*R+1.)
      IF (Q.LT.0.0) THEN
        ENORM=-R
      ELSE
        ENORM=R
      ENDIF
      RETURN
      END

```

```

      FUNCTION FLNORM(U, V, R)

```

```

C *****
C COMPUTE THE INTEGRAL OF THE BIVARIATE NORMAL
C DISTRIBUTION UP TO LIMITS U AND V.
C REF OWEN, 1980: A TABLE OF NORMAL INTEGRALS,
C COMMON STATISTICS. -SIMULA-COMPUTA.,
C B9(4), 389-419, EQ 3.1.
DATA PI/3.1415926536/
IF (ABS(U).LT.1.0E-8 .AND. ABS(V).LT.1.0E-8) GO TO 999
H=-U
XK=-V
Y=(PNORM(H)+PNORM(XK))/2.
IF (H.LT.0. .AND. XK.GE.0.) Y=Y-.5
IF (XK.LT.0. .AND. H.GE.0.) Y=Y-.5
Y=Y-TFUNC2(H, XK-R*H, H*SQRT(1.-R*R)) -
X TFUNC2(XK, H-R*XK, XK*SQRT(1.-R*R))
FLNORM=Y
RETURN
999 FLNORM=.25+ASIN(R)/(2.*PI)
RETURN
END
END OF FILE

```